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Irrigation Industry Association
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Ministry of Agriculture and Fisheries
ENGINEERING BRANCH

# B.C. TRICKLE IRRIGATION MANUAL

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# B.C. TRICKLE IRRIGATION MANUAL

## I INTRODUCTION

Trickle irrigation is the frequent, low pressure application of water placed near or directly into the plants' root zone. Water is generally applied at a low flow rate but in an amount sufficient to replenish the crop water requirement on a daily basis.

Basic trickle irrigation system components include a filtration system, flow meter, mainline, header lines, pressure reducing valves, lateral lines and emitters. An emitter is the device used to precisely regulate the flow rate at each discharge point. Emission devices can be classed into three catagories:

> Linear tape system - consists of inexpensive plastic hose with built in orifices spaced along its length.
>
> Point source emitter system - consists of a drip hose that utilizes emitters to regulate flow and discharge water as a point source.
>
> Spray emitter system - consists of a drip hose using emitters that apply water at a higher rate than point source systems and distribute water by means of a spray pattern.

Linear tape and point source emitter systems rely on the combined forces of gravity and capillarity to move water laterally and dowrward through the root zone.

A good system design is the first step towards successfully implementing a trickle irrigation project. Due to the low pressure requirement of a trickle system, elevation differences and excessive friction losses can severely effect uniformity of application. To ensure adequate moisture distribution throughout the entire field, trickle systems should be designed to a uniformity of 90%. This can only be accomplished by designing the system to match soil conditions, crop characteristics, field shapes and topographies; selecting the right types of components based on a knowledge of emitter performance; and installing the system accurately as per plan.

This manual is produced to provide the irrigation industry, both designer and user, with guidelines on design and operation of trickle irrigation systems in British Columbia.

The following topics are covered in the manual.

**Plant Water Requirements**

> Maximum British Columbia crop water requirements must be determined to ensure that the trickle system design will be capable of supplying sufficient water during peak use periods. This section outlines a method of calculating peak water requirements on a per plant basis.

**Lateral and Mainline Design**

Tables, graphs and charts have been included to assist in the design and selection of adequate lateral and mainline piping. Lateral line design information includes linear tape, point source and spray emitter type systems.

**Greenhouse Systems**

A special section is included for greenhouse system design. Plant water requirements, lateral design and operating sequences for greenhouse trickle systems differ substantially from orchard or row crop type systems.

**Emitter Selection**

Information on the various types of emitters available and the methods of pressure reduction are explained. The selection of the best emitter must take into account emitter pressure reducing principles, type of installation, water quality and crop type.

**Pump and Mainline Design**

This section, as well as the appendices, contain information on selecting pump and mainline sizes. Charts and tables are included to assist the designer in calculating total head requirements.

**Water Treatment Requirements**

Trickle irrigation systems are susceptible to plugging caused by particulates in the water supply as well as chemical precipitates and algae growth caused by Calcium, Magnesium, Iron and Sulpher concentrations. This section provides information on filtration requirements and the chemical treatment necessary to keep trickle irrigation systems operating smoothly.

**Chemical Injection**

Trickle irrigation systems are ideal for precise application of fertilizers, nematocides and other chemicals. The addition of acids and chlorine to the water are required in some instances to reduce chemical precipitation and algae buildup. There are different methods of injecting chemicals into the trickle irrigation system. This section identifies injection methods and provides information on backflow prevention requirements.

**Monitoring Soil Moisture**

Scheduling of trickle irrigation systems continues to be a major management problem. This section outlines some of the "tools" that can be used in making trickle irrigation scheduling decisions.

A glossary of terms is given at the back of the manual. The manual is presented in British units except where manufacturers use metric terminology. A conversion table is included in the back to assist in metric conversion. **Unless otherwise specified all volumes are in U.S. gallons.** A flow chart indicating the steps to assist in trickle irrigation design is shown on the next page.

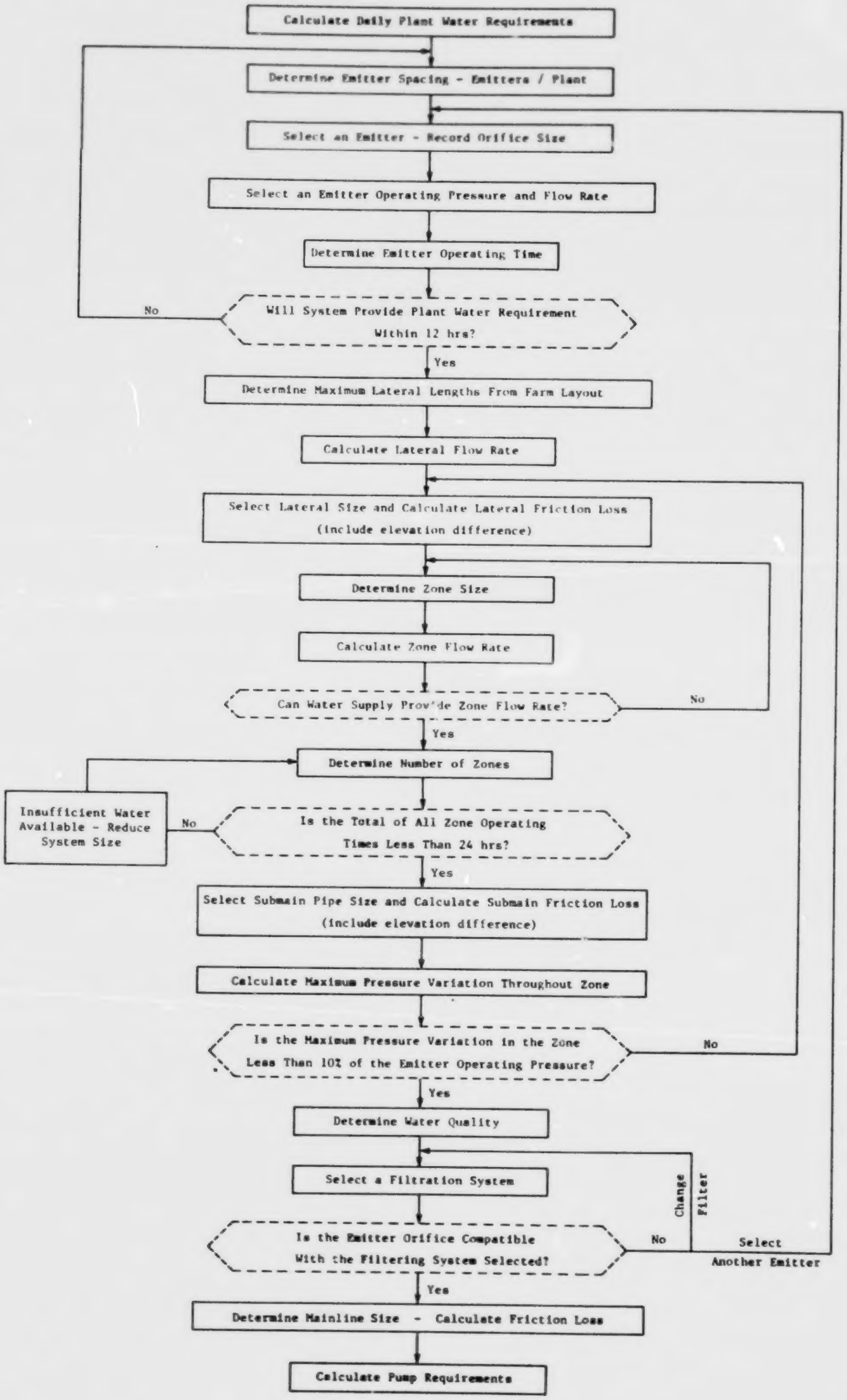

Calculate Daily Plant Water Requirements
Determine Emitter Spacing - Emitters / Plant
Select an Emitter - Record Orifice Size
Select an Emitter Operating Pressure and Flow Rate
Determine Emitter Operating Time
No
Will System Provide Plant Water Requirement Within 12 hrs?
Yes
Determine Maximum Lateral Lengths From Farm Layout
Calculate Lateral Flow Rate
Select Lateral Size and Calculate Lateral Friction Loss (include elevation difference)
Determine Zone Size
Calculate Zone Flow Rate
Can Water Supply Provide Zone Flow Rate?
No
Yes
Determine Number of Zones
Insufficient Water Available - Reduce System Size
No
Is the Total of All Zone Operating Times Less Than 24 hrs?
Yes
Select Submain Pipe Size and Calculate Submain Friction Loss (include elevation difference)
Calculate Maximum Pressure Variation Throughout Zone
Is the Maximum Pressure Variation in the Zone Less Than 10% of the Emitter Operating Pressure?
No
Yes
Determine Water Quality
Select a Filtration System
Change Filter
Is the Emitter Orifice Compatible With the Filtering System Selected?
No
Select Another Emitter
Yes
Determine Mainline Size - Calculate Friction Loss
Calculate Pump Requirements

Figure 1.1 Flow Chart for Designing A Trickle Irrigation System

# II ORCHARD, VINEYARD, BERRY AND ROW CROP TRICKLE SYSTEM DESIGN

A trickle system should be designed to match the anticipated peak evapotranspiration rate of the crop. The system design capacity, the maximum flow rate which the system can supply to the crop, is established by the plant water requirement, emitter selection, lateral line design, header design and filtration system capabilities. A trickle system should never be designed for 24 hours of operation per day. The total system operating time should not exceed 20 hours/day to compensate for a reduction in system flow rate over time. As system flow rates decrease over time, system operating times must increase in order to supply an equivalent volume of water to each plant. This would not be possible if the system is designed to operate 24 hours per day.

## 2.1 PLANT WATER REQUIREMENTS

Trickle system design must take into account:

### Climatic conditions

The peak evapotranspiration rate will normally occur during the hottest period of the growing season. The system design must be based on this peak rate.

### Crop maturity

On all crops, plant water requirement will increase with plant growth and leaf coverage. The system design capacity must be based on the irrigation requirements of a mature crop.

### Crop type

Water requirements for various plants will vary due to plant size, plant spacing, leaf area and type of leaf surface.

### Effective Soil Water Storage

The effective soil water storage capability should be calculated. The effective soil water storage is the volume of water stored in the soil which is readily available for use by the plant. It is a function of soil type, plant rooting depth and the plant's ability to extract water from the soil.

When the effective soil water storage is low, the trickle system design capacity must be based on the peak evapotranspiration rates that occur. However, if the effective soil water storage is high, the plant has a larger water reservoir upon which it can draw. In these situations the system design capacity can be reduced as the amount of water supplied does not have to match the peak evapotranspiration rates that occur. The percentage reduction will depend upon crop rooting depth, crop type and soil conditions. The soil water storage factor (S) takes this into account in the G/P/D formula on page 2-2.

### Leaching Requirement

To prevent the buildup of salts within the wetted plant root volume, a 10% leaching requirement must be built into the design of the system. The trickle system manager must apply enough water during the irrigation season to ensure that leaching of salts does occur. A 10% leaching factor is suggested!

### Application Efficiency

Trickle irrigation systems are considered to be approximately 90% efficient. (Compared to 70-75% for sprinkler irrigation systems and even less for flood irrigation). Efficiency will vary with the method of installation. The system design capacity must take the trickle system efficiency into consideration.

## Trickle System Design Requirements

The plant water requirement for a trickle irrigation system design is expressed as gallons/plant/day (G/P/D/). It is calculated by the formula:

$$G/P/D = 0.623 \times ET \times S \times A \times K$$

where $$0.623 = \frac{27{,}152 \text{ gal./ac-in}}{43{,}560 \text{ ft}^2\text{/acre}}$$

ET = Peak evapotranspiration rate for location (in/day) (Table 2.5)

S = Factor taking into account effective soil water storage (Table 2.4)

A = Plant area (ft$^2$) - calculated from plant spacing

K = Crop coefficient factor (Table 2.6)

Two factors that require further explanation are the effective soil water storage factor (S) and the crop coefficient factor (K).

### Calculating the Effective Soil Water Storage Factor (S)

The effective soil water storage capacity of the plant root zone depends upon

(i) the available water storage capacity of the soil (Table 2.1)
(ii) effective rooting depth of mature crops under a trickle irrigation system (Table 2.2)
(iii) the availability of the stored water to the crop (Table 2.3)

Table 2.1 Guide To Available Water Storage Capacities of Soils

| Textural Class | Available Water Storage Capacity in Inches of Water per Foot of Soil |
|---|---|
| Sand | 1.0 |
| Loamy Sand | 1.2 |
| Sandy Loam | 1.5 |
| Fine Sandy Loam | 1.7 |
| Loam | 2.1 |
| Silt Loam | 2.5 |
| Clay Loam | 2.4 |
| Clay | 2.4 |
| Organic Soils (muck) | 3.0 |

Table 2.2 Effective Rooting Depth of Mature Crops Under Trickle Irrigation

| Shallow 1.5 ft | Medium Shallow 2 ft | Medium Deep 3 ft | Deep 4 ft |
|---|---|---|---|
| Cabbages | Beans | Brussels Sprouts | Asparagus |
| Cauliflowers | Beets | Corn (sweet) | Blackberries |
| Cucumbers | Blueberries | Eggplant | Grapes |
| Lettuce | Broccoli | Kiwifruit | Loganberries |
| Onions | Carrots | Peppers | Raspberries |
| Radishes | Celery | Squash | Sugar Beets |
| Turnips | Potatoes | | Tree Fruits |
| | Peas | | |
| | Strawberries | | |
| | Tomatoes | | |

Table 2.3 Availability Coefficient to Determine Plant Water Use Capabilities

| Crop | Maximum Percent (%) |
|---|---|
| Peas | 35 |
| Potatoes | 35 |
| Tree Fruits | 40 |
| Grapes | 40 |
| Tomatoes | 40 |
| Other crops until additional data becomes available | 50 |

**Example 1:**

Calculate the effective soil water storage capacity of a loam soil growing tree fruits.

| From: | | | |
|---|---|---|---|
| | Table 2.1 | Available Water Storage Capacity for loam | = 2.1 in/ft |
| | Table 2.2 | Rooting depth of tree fruits | = 4 ft |
| | Table 2.3 | Availability Coefficient | = 0.40 |

$$\text{Effective soil water storage capacity} = 2.1 \frac{\text{in}}{\text{ft}} \times 4 \text{ ft} \times 0.40$$

$$= 3.36 \text{ in}$$

The soil water storage factor (S) is dependent upon the effective soil water storage capacity and peak evapotranspiration rate (Table 2.5). Soils and crops that produce a high effective storage capacity will have a lower (S) factor as the crop has more water to draw on during peak conditions. Very low effective storage capacity conditions will have a high (S) factor (close to 1.0). The (S) factor will also increase as the peak evapotranspiration rate increases.

Table 2.4 Effective Soil Water Storage Factor (S)

| Effective Soil Water Storage Capacity | Peak Evapotranspiration Rate | S Factor |
|---|---|---|
| 3.0 inches + | 0.30 in/day | 0.80 |
| | 0.25 | 0.75 |
| | 0.20 | 0.75 |
| 2.0 inches | 0.30 | 0.85 |
| | 0.25 | 0.80 |
| | 0.20 | 0.75 |
| 1.0 inches | 0.30 | 0.95 |
| | 0.25 | 0.90 |
| | 0.20 | 0.85 |

Example 1 continued:

Select the soil water storage factor (S) for a tree fruit crop growing in a loam soil with a peak ET rate of 0.24 in/day.

- The effective soil water storage capacity has been calculated above as 3.36 inches.
- From Table 2.4 the effective soil water storage factor (S) would be 0.75

Table 2.5 **Peak Evapotranspiration (ET) for Trickle Irrigation Design**

| Location | ET (in/day) | Location | ET (in/day) |
|---|---|---|---|
| Abbotsford | .15 | Kettle Valley | .27 |
| Agassiz | .15 | Kimberley | .30 |
| Alexis Creek | .15 | Ladner | .13 |
| Armstrong | .21 | Langley | .14 |
| Ashcroft | .30 | Lillooet | .28 |
| Aspen Grove | .21 | Lister | .21 |
| Barriere | .20 | Lumby | .23 |
| Baynes Lake | .25 | Lytton | .30 |
| Campbell River | .20 | Malakwa | .19 |
| Canal Flat | .26 | Merritt | .26 |
| Castlegar | .31 | Nanaimo | .19 |
| Cawston | .32 | Natal | .18 |
| Chase | .21 | Notch Hill | .20 |
| Cherryville | .21 | Oliver | .26 |
| Chilliwack | .17 | 100 Mile House | .23 |
| Clinton | .23 | Osoyoos | .28 |
| Cloverdale | .14 | Oyster River | .12 |
| Comox | .20 | Parksville | .16 |
| Creston | .18 | Pitt Meadows | .13 |
| Donald | .14 | Port Alberni | .20 |
| Douglas Lake | .21 | Prince George | .15 |
| Duncan | .16 | Princeton | .25 |
| Ellison | .23 | Quesnel | .26 |
| Fort Fraser | .19 | Radium | .20 |
| Fort Steele | .22 | Riske Creek | .28 |
| Golden | .15 | Saanichton | .16 |
| Grand Forks | .19 | Salmon Arm | .17 |
| Grandview Flats | .25 | Smithers | .15 |
| Grasmere | .22 | Spillimacheen | .19 |
| Grinrod | .14 | Sumas | .17 |
| Hazelton | .19 | Summerland | .26 |
| Hixon | .16 | Terrace | .30 |
| Hope | .22 | Vancouver | .18 |
| Invermere | .23 | Vanderhoof | .20 |
| Joe Rich | .16 | Vavenby | .16 |
| Jura | .22 | Vernon | .22 |
| Kamloops | .28 | Walhachin | .29 |
| Kelowna | .24 | Westwold | .27 |
| Keremeos | .29 | Williams Lake | .28 |
| Kersley | .22 | | |

## Selecting a Crop Coefficient Factor

The crop coefficient factor (K) accounts for the field area that is not utilized by the plants' canopy or root area. The crop coefficient factors listed are for mature crops and can only be used in the design process if actual plantings closely approximate the plant spacings shown in the table. For larger plant spacings the crop coefficient factors may possibly be reduced.

Table 2.6 Crop Coefficient Factor (K)

| Plant | Crop Coefficient | Appropriate Spacings |
|---|---|---|
| Apples | 0.90 | 8'x16' to 20'x20' |
| Apricots | 0.80 | |
| Cherries | 0.90 | |
| Peaches | 0.80 | |
| Pears | 0.80 | |
| Plums | 0.80 | |
| Grapes | 0.70 | 5' x 12' |
| Blueberries | 0.80 | 5' x 10' |
| Blackberries | 0.60 | 8' x 10' |
| Kiwi Fruit | 1.00 | 15' x 15' |
| Logan Berries | 0.60 | 8' x 10' |
| Raspberries | 0.70 | 2.5' x 10' |
| Strawberries | 0.75 | 1' x 4' |
| Tomatoes | 0.90 | 1.5' x 5' |
| Vegetables | 0.75 | 1' x 3' |

## Calculation of Plant Water Requirement

**Example 1 continued:**

An apple crop, on a 10ft x 20ft planting is grown in Kelowna in a loam soil. What is the plant water requirement during the peak of the season?

$$G/P/D = 0.623 \times ET \times S \times A \times K$$

| | | | |
|---|---|---|---|
| From: | Table 2.1 | Soil Water Storage Capacity | = 2.1 in/ft |
| | Table 2.2 | Rooting depth of mature crop | = 4 ft |
| | Table 2.3 | Availability Coefficient | = 0.40 (40%) |
| | Effective Soil Water Storage Capacity | | = 2.1 in x 4 ft x 0.40<br>= 3.36 inches |
| From: | Table 2.5 | Peak ET | = 0.24 in/day |

Table 2.4 - Based on a 0.24 ET rate and an effective water storage capacity of 3.36 an S factor of 0.75 is selected.

Table 2.6 Crop coefficient factor K = 0.90

Plant area (A) = 10ft x 20ft = 200 $ft^2$

$$G/P/D = 0.623 \times (0.24) \times 0.75 \times 200 \times 0.90$$

$$= 20.2 \text{ gallons per plant per day}$$

## Calculating Trickle System Design Requirement

The trickle system design requirement must take into account the plant water requirement (G/P/D), a necessary leaching factor to ensure that salts do not build up within the plant's root zone, and an application efficiency.

The trickle system design requirement is calculated from the formula:

$$TC = \frac{G/P/D \times L}{E}$$

where TC = trickle system design capacity
G/P/D = plant water requirement
L = leaching factor
E = application efficiency

Trickle irrigation systems are approximately 90% efficient. To reduce the potential of excessive salt buildup a leaching factor of 10% is normally used. The trickle system capacity should therefore include factors of L = 1.10 and E = 0.90.

**Example 1 continued:**

$$TC = \frac{20.2 \times 1.10}{0.90} = 24.7 \text{ gallons per plant per day}$$

## Comparison of Trickle Design Requirements of Various Crops

The amount of water to be applied to a parcel of land by a trickle irrigation system will depend upon climatic conditions, soil characteristics, crop type, and plant spacings. As shown in examples 1, 2 and 3 the plant water requirement varies dramatically depending on location, plant spacing and crop type.

### Example 2

A raspberry crop, on a 2.5 ft x 10 ft planting is grown in Abbotsford in a sandy loam soil. What is the plant water requirement during the peak of the irrigation season?

$$G/P/D = 0.623 \times ET \times S \times A \times K$$

From Table 2.1 Soil Water Storage Capacity = 1.5 in/ft

Table 2.2 Rooting depth of mature crop = 4 ft

Table 2.3 Availability Coefficient = 0.50

Effective soil water storage capacity = 1.5 in/ft x 4 ft x 0.50
= 3 inches

Table 2.5 Peak ET rate = 0.15 in/day

Table 2.4 Soil water storage factor = 0.75 (Based on 3 in storage capacity and an ET rate of 0.15 in/day)

Table 2.6 Crop Coefficient Factor K = 0.70

Plant area A = 2.5 ft x 10 ft = 25 ft$^2$

$$G/P/D = 0.623 \times 0.15 \times 0.75 \times 25 \times 0.70$$

$$= 1.25 \text{ gallons per plant per day}$$

The trickle system design requirement (TC) will be:

$$TC = \frac{1.25\ G/P/D \times 1.10}{0.90} = 1.5 \text{ gallons per plant per day}$$

### Example 3

Kiwi fruit, on a 15 ft x 15 ft planting is grown in Saanichton in a loamy sand soil. What is the plant water requirement during the peak of the irrigation season?

$$G/P/D = 0.623 \times ET \times S \times A \times K$$

From Table 2.1 Soil Water Storage Capacity = 1.2 in/ft
Table 2.2 Rooting depth of mature crop = 3 ft
Table 2.3 Availability Coefficient = 0.50

Effective soil water storage capacity = 1.2 in/ft x 3 ft x 0.50
= 1.8 in

Table 2.5 Peak ET rate = 0.16 in/day
Table 2.4 Soil water storage factor (S) = 0.75
Table 2.6 Crop coefficient factor (K) = 1.00
Plant Spacing (A) = 15 ft x 15 ft = 225 ft

G/P/D = 0.623 x 0.16 x 0.75 x 225 x 1.0

= 16.8 gallons per plant per day

The trickle system design requirement (TC) will be:

$$TC = \frac{16.8 \text{ G/P/D} \times 1.10}{0.90} = 20.5 = 21 \text{ gallons per plant per day}$$

**Comparing Crop Water Requirements**

Due to the variance in water requirements of different crops, a trickle system designed for a certain crop is not necessarily transferable to another crop, even if both crops are grown under the same soil and climatic conditions. A trickle system must be designed for the specific site conditions that exist. This is exemplified in Table 2.7. Note the daily per acre water requirement of various crops at peak conditions assuming the same soil and climatic conditions. (Plant spacings chosen are assumed to be typical of the industry). **The water requirements shown in Table 2.7 are for the specific soils and climatic conditions stated.** They are to be used for illustrative purposes only. The purpose of the table is to indicate that different crops will require various supply rates even when climate and soil conditions remain the same.

Table 2.7 Plant Water Requirements per Acre Based on a Sandy Loam Soil and an ET rate of 0.20 in/day

| Crop | Plant Spacing | G/P/D | Plants /Acre | Daily Acreage Water Requirement |
|---|---|---|---|---|
| Apples | 15' x 20' | 25.2 | 145 | 3650 gal/ac |
| Grapes | 5' x 12' | 3.9 | 726 | 2830 |
| Raspberries | 2.5' x 10' | 1.7 | 1,743 | 2960 |
| Strawberries | 1' x 4' | 0.3 | 10,890 | 3270 |
| Tomatoes | 1.5' x 5' | 0.7 | 5,808 | 4070 |
| Kiwi Fruit | 15' x 15' | 21.0 | 194 | 4075 |

**The above water requirements do not include application efficiency or a leaching factor.**

### Mulches and Minitunnels

Mulches and minitunnels are used on row crops to enhance the plant's environment, especially in the early part of the growing season. Trickle irrigation systems are compatible with this type of technology and are used to supply the water and nutrients to the crop. Plant water usage in this enclosed environment is usually reduced. The amount of reduction has not been accurately determined.

In the case of minitunnel systems, the plastic cover is quite often removed later in the growing season. Trickle irrigation systems in mulch and minitunnel installations should therefore be designed for field conditions. Although the systems may be overdesigned in some instances, a grower can be assured that the system capacity will be able to supply enough water during peak conditions, whether the plastics are used or not.

## 2.2 TRICKLE SYSTEM DESIGN PARAMETERS

Once the trickle system design requirement has been calculated, the emitter type, discharge rate and spacing must be selected. Chapter 4 covers in more detail the selection of an emitter to match the crop, soil and emission uniformities that are required to ensure a good trickle system design. Chapters 5 and 9 provide additional information on system installation and scheduling.

This section is included to illustrate basic design parameters once an emitter type has been selected. A procedure for calculating operating times and zone sizes is outlined. **Linear tape system specifications are shown under lateral design, Section 2.3.**

### Point Source Emitter System Specifications

#### Example 1a

An apple crop in Kelowna on a 10' x 20' planting is grown in a loam soil.

| | |
|---|---|
| Trickle System Design Requirement | 24.7 G/P/D from page 2-7. |
| Tree Spacing | 10 ft x 20 ft |
| Row Length | 400 ft |
| Number of rows | 100 |
| Irrigation District Allotment | 90 gpm |

| | |
|---|---|
| Emitter selected | point source 1 gph emitter |
| Emitter spacing | 4 ft along the row |
| Emitter operating pressure | 15 psi |

Water supplied per row = $\frac{\text{row length(ft) x emitter flow rate (gph)}}{\text{emitter spacing(ft)}}$

= $\frac{\text{400 ft x 1 gph}}{\text{4 ft}}$ = 100 gph/row

= 1.67 gpm/row

Number of rows/zone = $\frac{\text{Water Allotment (gpm)}}{\text{Flow rate per row (gpm)}}$

= $\frac{\text{90 gpm}}{\text{1.67 gpm/row}}$

= 53 rows/zone

Number of zones = $\frac{\text{total rows}}{\text{rows/zone}}$

= $\frac{\text{100 rows}}{\text{53 rows zone}}$

= 2 zones

Water Requirement per row per day

= Trickle System Design Requirement/tree x trees/row

= 24.7 G/P/D x 40 trees/row

= 988 gal/row/day

Application time per zone per day

= $\frac{\text{gal/row/day}}{\text{gph/row}}$

= $\frac{\text{988 gal/row/day}}{\text{100 gph/row}}$

= 9.9 hr/day

* Total hours of irrigation per day

= number of zones x application time per zone per day

= 2 x 9.9 hr

= 19.6 hr/day

## Spray Emitter System Specifications

### Example 1b

A tree fruit crop in Kelowna on a 10 ft x 20 ft planting is grown in a loam soil.

| | |
|---|---|
| Trickle system design requirement | 24.7 G/P/D from page 2-7 |
| Row length | 400 ft |
| Tree spacing | 10 ft x 20 ft |
| Number of rows | 100 |
| Irrigation district allotment | 90 gpm |
| Emitter selected | 4.8 gph - 180° spray emitters (table 6.2) |
| Emitter spacing | 2 emitters per tree - one on each side of the tree |
| Emitter operating pressure | 15 psi |

$$\text{Water supplied per row} = \frac{\text{row length(ft) x emitter flow rate (gph)}}{\text{emitter spacing (ft)}}$$

$$= \frac{\text{400 ft x (2 emitters x 4.8 gph/emitter)}}{\text{10 ft}}$$

$$= \text{384 gph/row} = \text{6.4 gpm/row}$$

$$\text{Number of rows/zone} = \frac{\text{Water allotment (gpm)}}{\text{Flow rate per row (gpm)}}$$

$$= \frac{\text{90 gpm}}{\text{6.4 gpm/row}} = \text{14 rows/zone}$$

$$\text{Number of zones} = \frac{\text{total rows}}{\text{rows/zone}}$$

$$= \frac{\text{100 rows}}{\text{14 rows/zone}} = \text{7.1 zones} = \text{8 zones}$$

Water requirement per row per day

= Trickle System Design Requirement (gph/tree) x trees/row
= 24.7 G/P/D x 40 trees/row
= 988 gal/row/day

Application time per zone per day

$$= \frac{\text{gal/row/day}}{\text{gph/row}} = \frac{988}{384} = \text{2.6 hr/zone/day}$$

*Total hours of irrigation per day

= number of zones x application time/zone/day
= 8 x 2.6 hr/zone
= 20.8 hr/day

* Note that this is the maximum application required during the peak time of the irrigation season. Also the trickle system layout may require actual lateral lengths to be reduced from the 400 foot row length due to lateral line friction losses (See Section 2.3).

Examples 1a and 1b illustrate a major difference between point source and spray emitter systems. Spray emitter discharges are at least 5 times higher than point source emitter systems. Due to the higher flow rate requirements for spray emitter systems, operation and design parameters compared to point source systems will vary. Spray emitter systems:

- have shorter operating times
- require more zones or higher system flow rates per acre
- require larger lateral lines to accommodate the higher flow rates (See section 2.3 examples 1a and 1b)
- usually have shorter allowable lateral lengths
- are not pressure compensating and therefore cannot operate on undulating terrain.

## 2.3 LATERAL LINE DESIGN

Once the maximum pressure range has been determined the lateral and header lines can be designed. The total friction loss and elevation differences throughout a zone must not exceed the maximum allowable pressure range. Various lateral design methods can be used for different types of trickle systems.

### Spray and Point Source Emitter System Lateral Design

If single sized polyethylene laterals are used, the laterals can be designed using specific discharge rate curves (Appendix A). The specific discharge rate (SDR) of a lateral line is calculated by:

$$SDR = \frac{\text{total lateral flow (gph)}}{\text{lateral length (ft)}}$$

**If a lateral line is to consist of dual or multi pipe sizes the uniplot curves in Appendix D must be used to design the lateral line.**

An emitter barb friction loss should be added to the lateral friction loss in order to obtain the overall lateral pressure loss due to friction. A barb loss is estimated by taking 30% of the lateral line friction loss.

## Example 1a

A tree fruit crop on a 10 ft x 20 ft planting is grown in Kelowna on flat topography in a loam soil. The trickle system design requirement has been calculated to be 24.7 G/P/D (from page 2-7).

The trickle system design parameters are:

| | |
|---|---|
| Tree spacing | 10 ft x 20 ft |
| Row length | 400 ft |
| Number of rows | 100 |
| Irrigation Allotment | 90 gpm |
| Emitter selected | 1 gpm point source emitter |
| Emitter spacing | 4 ft |
| Emitter Operating Pressure | 15 psi |

A trickle system uniformity (EU) of 90% is desired. The manufacturer's variance and the EU of 90% dictate that the maximum pressure range allowable is 20% of the emitter operating pressure. What size lateral line should be used?

$$\text{SDR} = \frac{\text{lateral flow}}{\text{lateral length}} = \frac{100 \text{ emitters/row} \times 1 \text{ gph}}{400 \text{ ft}} = 0.25 \text{ gph/ft}$$

$$\text{Pressure range} = 15 \text{ psi} \times 0.20 = 3 \text{ psi}$$

The pressure range includes lateral friction loss, submain (header) friction loss and elevation differences. Since the land is flat, the elevation effect is non-existent. Allowing a submain friction loss of 1.5 psi results in an allowable lateral friction loss of 1.5 psi.

From Figure A.3 - for an SDR of 0.25 gph/ft and a 400 ft row length the lateral friction loss for 15 mm PE is 6.5 ft = 2.8 psi (Note, this exceeds the allowable 1.5 psi)

From Figure A.6 - 20 mm PE has a friction loss of 1.5 ft = 0.65 psi

A lateral length of 400 ft will therefore require 20 mm PE. If 15 mm PE is to be used the submain will have to bisect the tree rows. A total lateral length of 200 ft will then result.

From Figure A.3 - 200 ft of 15 mm PE with an SDR of 0.25 gph/ft has a friction loss of 2 ft = 0.85 psi

Emitter Barb loss (30% of lateral loss) = 0.30 x 0.85 = 0.26 psi

Total lateral loss = 1.1 psi

The allowable submain loss is then 3 psi - 1.1 psi = 1.9 psi

### Example 1b

A tree fruit crop on a 10 ft x 20 ft planting is grown in Kelowna in a loam soil. The land has a slope of 2% in the direction of the row planting. The trickle system design parameters are similar to example 1a except spray emitters will be used.

| | |
|---|---|
| Emitter selected | 4.8 gph - $180^{\circ}$ spray emitters |
| Emitter spacing | 2 emitters per tree - one on each side of the tree trunk. |
| Emitter operating pressure | 15 psi |

A trickle system uniformity (EU) of 90% is desired. The manufacturer's variance and the EU of 90% dictate that the maximum pressure range allowable is 20% of the emitter operating pressure. What size lateral line should be used?

$$SDR = \frac{\text{lateral flow}}{\text{lateral length}} = \frac{80 \text{ emitters/row} \times 4.8 \text{ gph/emitter}}{400 \text{ ft}} = 0.96 \frac{\text{gph}}{\text{ft}}$$

Pressure range = 0.20 x 15 psi = 3 psi

Allowing a submain friction loss of 1.5 psi results in an allowable lateral friction loss of 1.5 psi.

From Figure A.6 - 400 ft of 20 mm PE with an SDR of
0.96 has a friction loss of 16.5 ft = 7.2 psi
(even with a pressure gain due to elevation, the
pressure loss would exceed 1.5 psi)

From Figure A.7 - 400 ft of 26 mm PE with an SDR of
0.96 has a friction loss of 5.5 ft = 2.4 psi

For a 2% slope the pressure gain on a 400 ft row is:
400 x 0.02 = 8 ft = 3.5 psi.

A 26 mm PE lateral therefore has a total pressure loss of:

friction loss = 2.40 psi

emitter barb loss = 0.30 x 2.4 psi = 0.72 psi

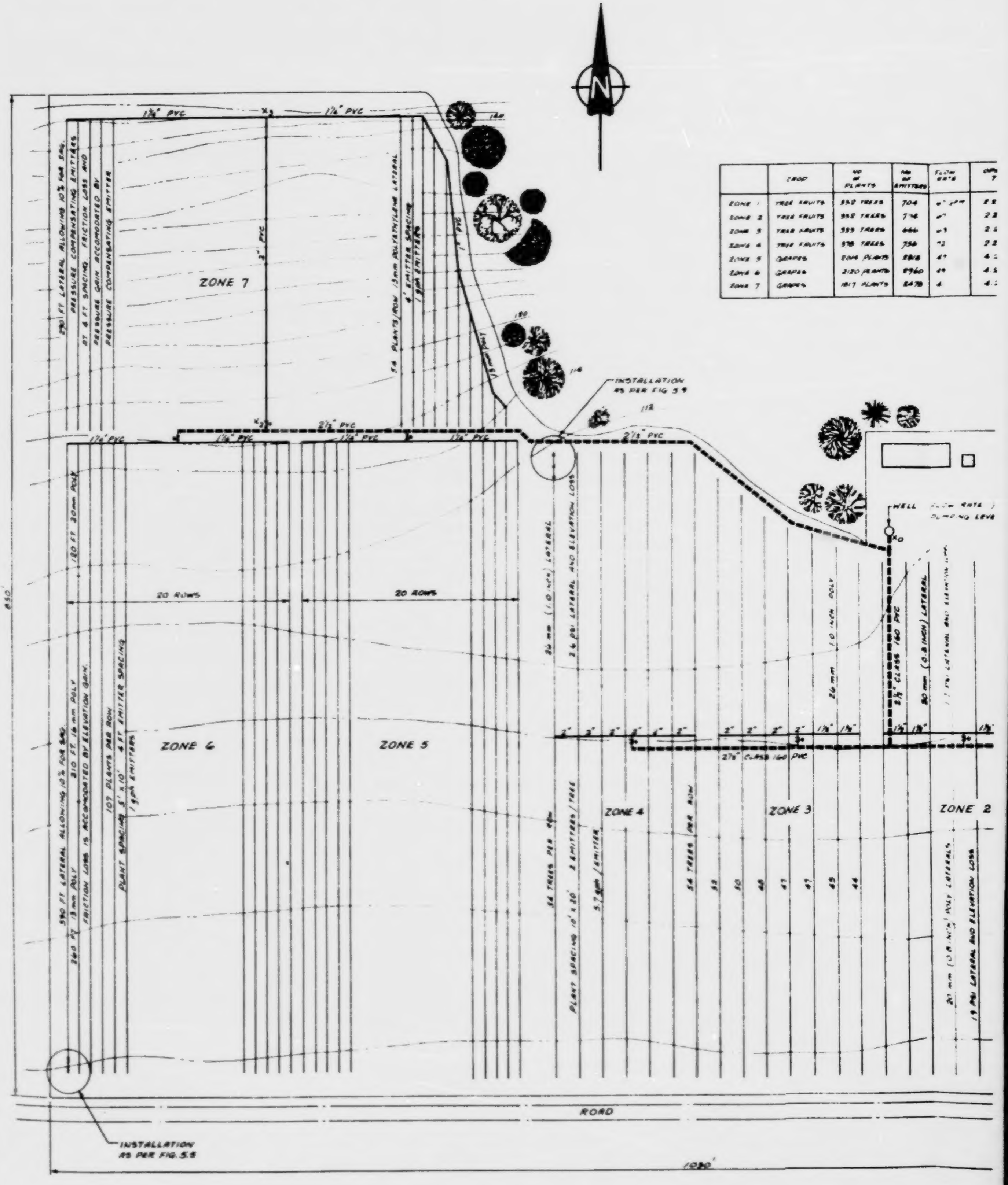
total friction loss 3.12 psi

minus elevation gain = 3.50 psi

net pressure variation along lateral is -0.38 psi

For a 2% slope, a 26 mm PE lateral operating the microjet system described in example 1b will have a pressure gain of 0.38 psi along a 400 ft lateral.

The emitter operating pressure along the lateral will change as lateral friction loss decreases down the lateral. The elevation pressure gain is uniform along the lateral. (At the beginning of the lateral friction loss may exceed elevation gain. Near the end of the lateral elevation gain exceeds friction loss.) Since the actual lateral loss is less than the 1.5 psi originally estimated, the allowable submain friction loss for this zone could be increased. The designer must be careful to ensure that



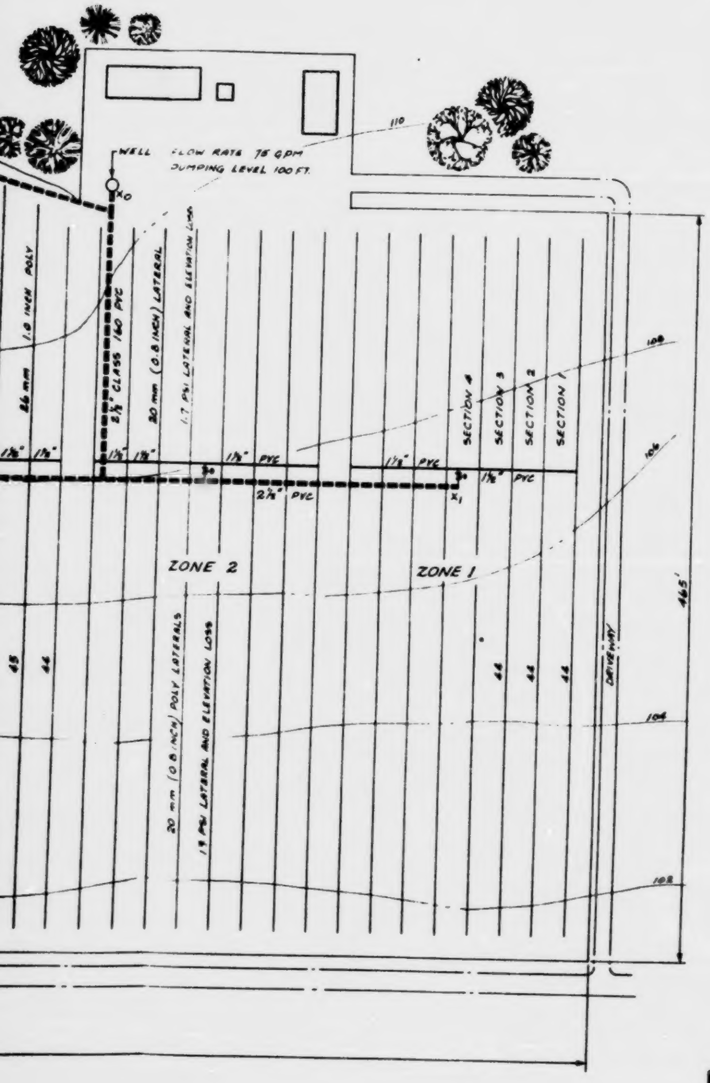
|  | CROP | NO OF PLANTS | NO OF EMITTERS | FLOW RATE | OPE |
|---|---|---|---|---|---|
| ZONE 1 | TREE FRUITS | 352 TREES | 704 | [illegible] gpm | 2.2 |
| ZONE 2 | TREE FRUITS | 358 TREES | 716 | [illegible] | 2.2 |
| ZONE 3 | TREE FRUITS | 333 TREES | 666 | [illegible] | 2. |
| ZONE 4 | TREE FRUITS | 378 TREES | 756 | [illegible] | 2.2 |
| ZONE 5 | GRAPES | 2014 PLANTS | 2818 | [illegible] | 4. |
| ZONE 6 | GRAPES | 2120 PLANTS | 2960 | [illegible] | 4. |
| ZONE 7 | GRAPES | 1817 PLANTS | 2478 | 4 | 4. |

**CAUTION!** THIS SAMPLE IRRIGATION PLAN IS FOR A SPECIFIC CROP, SOIL TYPE AND FARM LAYOUT AND IS TO BE USED FOR ILLUSTRATION PURPOSES ONLY.

Figure 2.1

Sample Point Source and Spray Emitter Design

| OP | NO OF PLANTS | NO OF EMITTERS | FLOW RATE | OPERATING TIME | PRESSURE SETTING AT ZONE | PRESSURE VARIATION |
|---|---|---|---|---|---|---|
| FRUITS | 352 TREES | 704 | 67 GPM | 2.2 HRS/DAY | 21.5 psi | 21.5 psi - 18.5 psi |
| FRUITS | 352 TREES | 704 | 67 | 2.2 | 21.5 | 21.5 - 18.5 |
| FRUITS | 333 TREES | 666 | 63 | 2.2 | 21.5 | 21.5 - 18.5 |
| FRUITS | 378 TREES | 756 | 72 | 2.2 | 21.5 | 21.5 - 18.0 |
| ES | 2014 PLANTS | 2818 | 47 | 4.2 | 17 | 17 - 15 |
| ES | 2120 PLANTS | 2960 | 49 | 4.2 | 17 | 17 - 15 |
| TS | 1817 PLANTS | 2470 | 41 | 4.2 | 31 | (PRESSURE COMPENSATING) |



## TRICKLE IRRIGATION DESIGN INFORMATION

**CROP AND SOILS REPORT**

| Pit | Crop | Root Depth (ft) | Availability Coefficient | Soil Texture | A.W.S.C. (in/ft) | Max Lateral Water movement. radius (ft) |
|---|---|---|---|---|---|---|
| A | TREE FRUITS | 4 FT | 0.40 | LOAM | 2.1 | 3.5 |
| B | GRAPES | 4 FT | 0.40 | LOAM | 2.1 | 2.5 |
| C | | | | | | |

**DESIGN PARAMETERS**

| | TREE FRUITS | | GRAPES |
|---|---|---|---|
| Evapotranspiration Rate (ET) | 0.24 | in/day | 0.24 |
| Effective Soil Water Storage Capacity | 3.4 | inches | 1.9 |
| Effective Soil Water Storage Factor (S) | 0.75 | | 0.80 |
| Plant Spacing | 10 × 20 | $\mathrm{ft}^2$ | 5 × 10 |
| Plant Area (A) | 200 | $\mathrm{ft}^2$ | 50 |
| Crop Coefficient Factor (K) | 0.90 | | 0.70 |

**PLANT WATER REQUIREMENTS**

Gallons/Plant/Day = 0.623 × $\frac{0.24}{(ET)}$ in/day × $\frac{0.75}{S}$ × $\frac{200}{A}$ $\mathrm{ft}^2$ × $\frac{0.90}{K}$ = 20.2 G/P/D    4.2

Trickle System Design Requirement TC = $\frac{G/P/D \times 1.1}{0.90}$ = 25 G/P/D    5.2

**DESIGN DATA**

| | | | |
|---|---|---|---|
| Emitter Type | SPRAY | | POINT SOURCE |
| Emitter Operating Pressure | 20 | psi | 15 |
| Emitter Discharge | 5.7 | gph | 1.0 |
| Emitter Spacing | 2 @ 10 | ft | 4 |
| Emitters per Plant | 2 | | 1.25 |
| Zone Operating Time per Day | 2.2 | hrs/day | 4.2 |
| Zone Flow Rate | 71 | gpm | 49 |
| Water Source Capacity | 75 | gpm | |
| Pressure at Water Source | 85 | psi | |

Total System Operating Time = 2.2 hrs/zone × 4 zones = 8.8 hrs
4.2 hrs/zone × 3 zones = 12.6 hrs = 21.4 hrs

**FILTRATION REQUIREMENTS**

| | | |
|---|---|---|
| Water Source | WOCID | |
| Water Quality Ca, Mg, Na, K | 5 | mg/l |
| Fe | – | mg/l |
| S | – | mg/l |
| pH | 6.8 | |

Screen Mesh Size or Sand Media Selection    150 MESH

**ZONE FRICTION LOSS CALCULATION** (FOR ZONE 1)

Maximum Pressure Variation in Zone    3.0 psi
Maximum Lateral Length    290 ft

Average Flow per foot in lateral = $\frac{\text{emitter flow rate}}{\text{emitter spacing}}$ = $\frac{5.7\ \text{gph}}{5\ \text{ft}}$ = 1.14 gph/ft

Lateral line friction loss =

290 ft - 0.8 inch poly pipe @ 1.14 gph/ft = 3.5 psi

Emitter Barb Loss (30% of lateral Line Loss) = 1.0 psi

Elevation Difference -6 ft = -2.6 psi

**Total Lateral Pressure Loss** = 1.9 psi

**Header Line Friction Loss**

| Section | Flow | Pipe Length | Pipe Size | Friction Loss |
|---|---|---|---|---|
| 1 | 8.4 gpm | 20 ft | 1½ in | 0.03 psi |
| 2 | 16.8 | 20 | 1½ | 0.19 |
| 3 | 25.2 | 20 | 1½ | 0.41 |
| 4 | 30.6 | 10 | 1½ | 0.19 |

Total Friction    0.82 psi

Header Line Fitting Loss (additional 20%)    0.16 psi

Elevation Difference 0 ft = 0 psi

**Total Header Line Pressure Loss**    0.98 psi

**Total Zone Pressure Loss**

Header Loss 0.98 psi + Lateral Line loss 1.9 psi = 2.88 psi

**MAINLINE FRICTION LOSS CALCULATION**

$x_0 - x_1$ 590 ' - 2½ " PVC @ 49 gpm - 5.9 × 0.52 = 3.0 psi
$x_1 - x_2$ 270 ' - 2 " PVC @ 41 gpm - 2.7 × 0.86 = 2.3 psi
x - x ___ ' - ___ " ___ @ ___ gpm - ___ × ___ = ___ psi
x - x ___ ' - ___ " ___ @ ___ gpm - ___ × ___ = ___ psi

Total Friction Loss in Mainline    5.3 psi

**SYSTEM PRESSURE REQUIREMENT**

Pressure Required at Zone Control    20 psi
Total Friction Loss in Mainline    5.3 psi
Elevation (INCLUDING WELL) 130 ft. = 56 psi
Miscellaneous Losses (Mainline valves, fittings, etc.)    3 psi

Total Pressure Requirement = 85 psi
= 196 ft

**SYSTEM FLOW REQUIREMENT**

72 gpm/zone × 1 zones operating at one time = 72 gpm

**HORSEPOWER REQUIREMENT**

H.P. = $\frac{200\ \text{ft} \times 75\ \text{gpm}}{3960 \times 0.68\ \%}$ = 6 h.p.

| DATE | REVISION |
|---|---|
| | |
| | |
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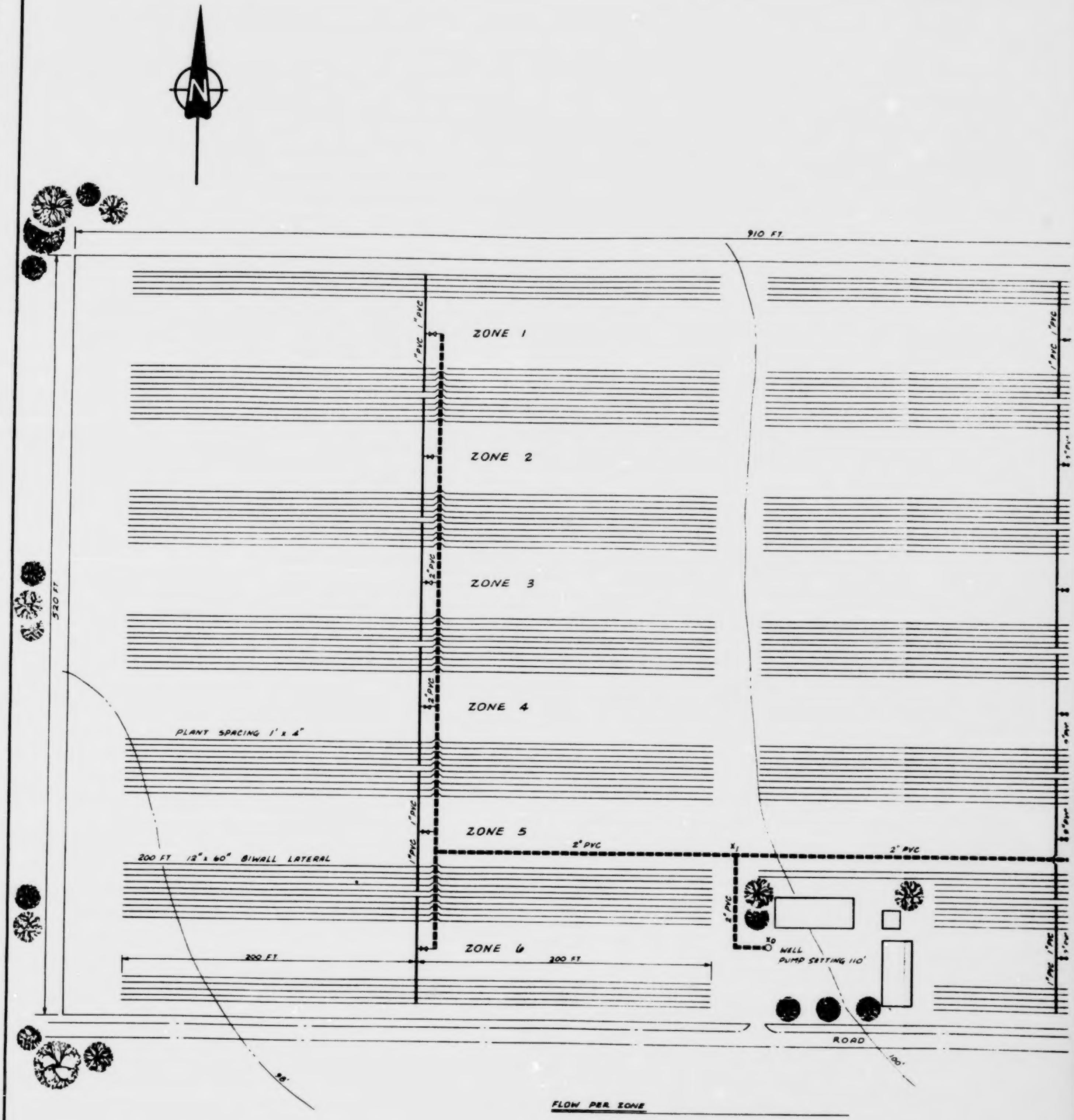
| | |
| | |

B.C. Ministry of Agriculture and Food
AGRICULTURAL ENGINEERING BRANCH

SAMPLE TRICKLE IRRIGATION PLAN
SPRAY AND POINT SOURCE
EMITTER SYSTEM

| | | | |
|---|---|---|---|
| DATE | AUGUST 1986 | SCALE | NTS. |
| DESIGNED | T VAN DER GULIK | SHEET | 1 OF 1 |
| DRAWN | L SCABAG | PLAN No. | 565.015 |
| CHECKED | | | |

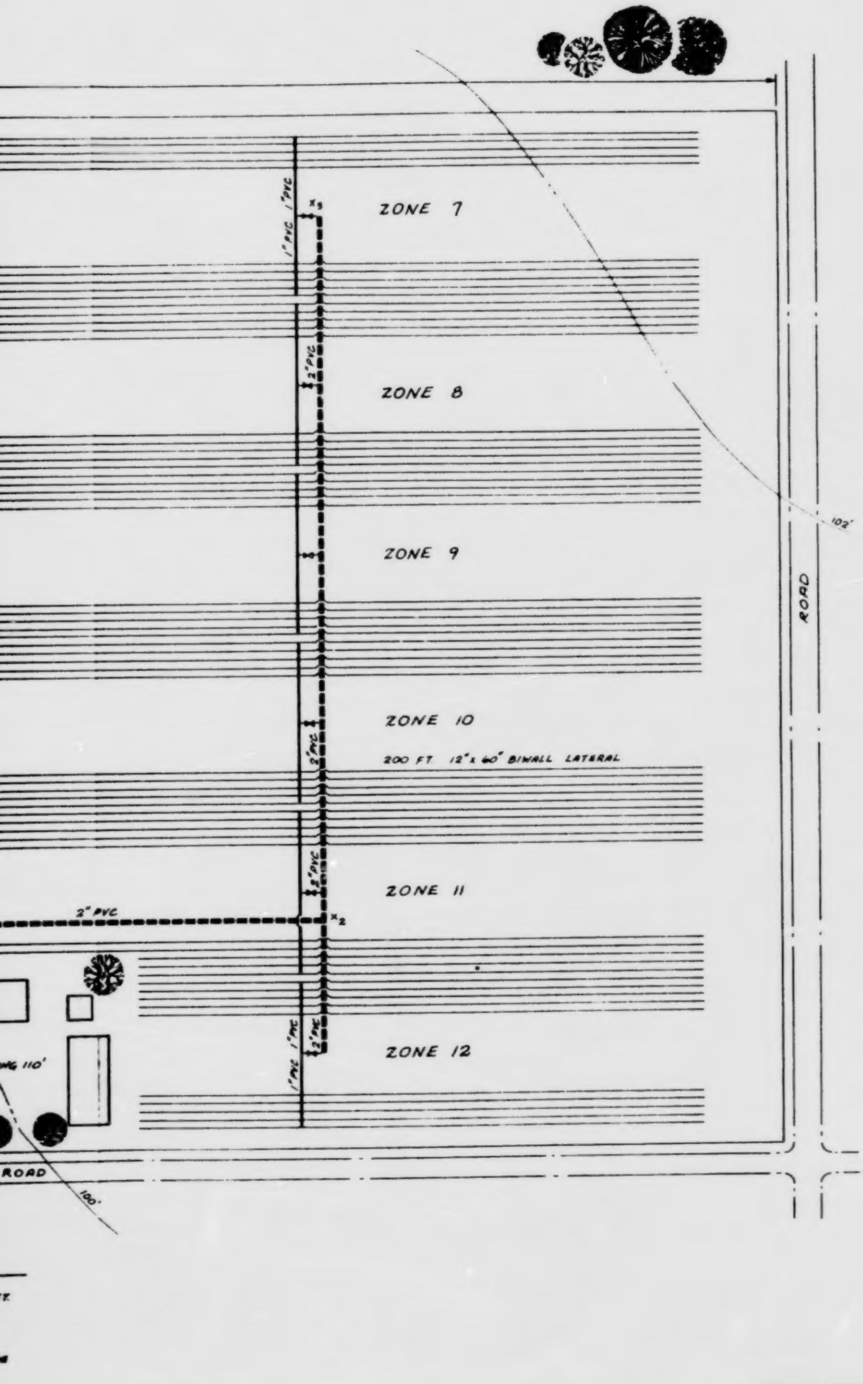


**FLOW PER ZONE**

| | |
|---|---|
| 200 FT. 12" x 60" BIWALL | = 66 gph/200 FT. |
| 21 ROWS PER ZONE @ 400 FT LENGTH | = 8400 FT |
| ALLOW 5% FOR EXPANSION | = 420 FT |
| | = 8820 FT/ZONE |
| 8820 FT x 66 gph/200 FT = 2910 gph | = 48.5 gpm |
| | = 50 gpm APPROX. |

**CAUTION!** THIS SAMPLE IRRIGATION PLAN IS FOR A SPECIFIC CROP, SOIL TYPE AND FARM LAYOUT AND IS TO BE USED FOR ILLUSTRATION PURPOSES ONLY.

**Sample Linear**



## TRICKLE IRRIGATION DESIGN INFORMATION

**CROP AND SOILS REPORT**

| Pit | Crop | Root Depth (ft) | Availability Coefficient | Soil Texture | A.W.S.C. (in/ft) | Max Lateral Water movement. radius (ft) |
|---|---|---|---|---|---|---|
| A | STRAWBERRIES | 2.0 | 0.50 | SANDY LOAM | 1.5 | 2.0 |
| B | " | 2.0 | 0.60 | " | 1.6 | 2.0 |
| C | " | 2.0 | 0.50 | " | 1.5 | 2.0 |

**DESIGN PARAMETERS**

| | |
|---|---|
| Evapotranspiration Rate (ET) | 0.15 in/day |
| Effective Soil Water Storage Capacity | 1.5 inches |
| Effective Soil Water Storage Factor (S) | 0.80 |
| Plant Spacing | 1 x 4 $ft^2$ |
| Plant Area (A) | 4 $ft^2$ |
| Crop Coefficient Factor (K) | 0.75 |

**PLANT WATER REQUIREMENTS**

Gallons/Plant/Day = 0.623 x $\frac{0.15}{(ET)}$ in/day x $\frac{0.80}{S}$ x $\frac{4}{A}$ $ft^2$ x $\frac{0.75}{K}$ = 0.22 G/P/D

Trickle System Design Requirement TC = $\frac{G/P/D \times 1.1}{0.90}$ = 0.27 G/P/D

**DESIGN DATA**

| | |
|---|---|
| Emitter Type | BIWALL 12" x 60" |
| Emitter Operating Pressure | 12 psi |
| Emitter Discharge | 66 gph/200 ft |
| Emitter Spacing | 1 ft |
| Emitters per Plant | LINE SOURCE |
| Zone Operating Time per Day | 0.82 hrs/day |
| Zone Flow Rate | 50 gpm |
| Water Source Capacity | 50 gpm |
| Pressure at Water Source | 40 psi |

Total System Operating Time = 0.82 hrs/zone x 12 zones = 9.8 hrs

**FILTRATION REQUIREMENTS**

| | | |
|---|---|---|
| Water Source | | WELL |
| Water Quality | Ca, Mg, Na, K | 10 mg/l |
| | Fe | 5 mg/l |
| | S | 0.01 mg/l |
| | pH | 7 |

Screen Mesh Size or Sand Media Selection 150 MESH

**ZONE FRICTION LOSS CALCULATION**

Maximum Pressure Variation in Zone 1.8 psi
Maximum Lateral Length 200 ft

Lateral line friction loss =

200 ft - 12" x 60 inch BIWALL pipe @ $\frac{1.0}{200}$ $\frac{gpm}{ft}$ = 0.4 psi

Emitter Barb Loss (10% of lateral Line Loss) = ______ psi

Elevation Difference 0 ft = 0 psi

Total Lateral Pressure Loss = 0.4 psi

Header Line Friction Loss

1" CLASS 160 PVC @ 25 gpm HAS A FRICTION LOSS OF 6.96 psi
40 ft @ 6.96 $\frac{psi}{100 ft}$ = 2.78 psi
FOR 10 OUTLETS (ON THIS 40 ft SECTION) FRICTION FACTOR = 0.385
HEADER FRICTION LOSS 2.78 psi x 0.385 = 1.07 psi

Total Friction 1.07 psi

Header Line Fitting Loss (additional 20%) 0.21 psi

Elevation Difference ______ ft = 0 psi

Total Header Line Pressure Loss 1.28 psi

Total Zone Pressure Loss

Header Loss 1.28 psi + Lateral Line loss 0.4 psi = 1.68 psi

**MAINLINE FRICTION LOSS CALCULATION**

$x_0$ - $x_1$ 65' - 2" PVC @ 50 gpm - 0.65 x 1.31 = 0.85 psi
$x_1$ - $x_2$ 220' - 2" PVC @ 50 gpm - 2.2 x 1.31 = 2.88 psi
$x_2$ - $x_3$ 150' - 2" PVC @ 50 gpm - 1.5 x 1.31 = 2.19 psi
x - x ____' - ____" ____ @ ____ gpm - ____ x ____ = ____ psi

Total Friction Loss in Mainline 5.92 psi

**SYSTEM PRESSURE REQUIREMENT**

| | | |
|---|---|---|
| Pressure Required at Zone Control | | 13.7 psi |
| Total Friction Loss in Mainline | | 6.0 psi |
| Elevation | 110 ft. = | 47.6 psi |
| Miscellaneous Losses (Mainline valves, fittings, etc.) | | 5 psi |
| Total Pressure Requirement | = | 72.3 psi |
| | = | 167 ft |

**SYSTEM FLOW REQUIREMENT**

50 gpm/zone x 1 zones operating at one time = 50 gpm

**HORSEPOWER REQUIREMENT**

H.P. = $\frac{167 \text{ ft} \times 50 \text{ gpm}}{3960 \times 0.62}$ = 3.5 h.p.

| DATE | REVISION |
|---|---|
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| | |
|---|---|
| B.C. Ministry of Agriculture and Food<br>AGRICULTURAL ENGINEERING BRANCH | |
| SAMPLE TRICKLE IRRIGATION PLAN<br>LINEAR TAPE SYSTEM<br>STRAWBERRIES | |
| DATE AUGUST 1986 | SCALE NTS |
| DESIGNED T. VAN DER GULIK | SHEET 1 OF 1 |
| DRAWN L. SCAGAR | PLAN No. 565.016 |
| CHECKED | |

Figure 2.2

Sample Linear Tape Trickle System Design the emitter operating pressure range does not exceed the maximum range determined for the emitter type used.

Note: Figure 2.1, page 2-16, provides an example plan of a point source emitter and spray emitter design. A blank Trickle Irrigation Design Information Sheet is available in Appendix E.

## Linear Tape Lateral Design

Linear tape laterals are manufactured with a range of wall thicknesses, orifice spacings and flow rates to match crop and site specific conditions.

Wall thickness determines the product durability. For an annual crop such as tomatoes a very light weight tubing may be the most economical. Strawberries may require a medium weight tubing, capable of withstanding a 3 - 4 year term. Heavier weight tubing is available for installation where mechanical, rodent, or field traffic abuse is more likely. Line source laterals are available in wall thicknesses from 4 mil to 25 mil (1 mil - 0.001 inch).

The orifice spacing selected is determined by the crop spacing and initial germination requirements. Crops that are planted close together may require linear tape systems with closely spaced orifices. The lateral and vertical water movement in the soil also is a factor in determining the orifice spacing.

The linear tape flow rate selected will depend upon the orifice spacing, operating pressure, length of lateral, and the crop water requirement. Selecting the lowest flow rate that is capable of doing the job will reduce friction losses and allow to obtain longer lateral lengths with better uniformity.

Linear tape lateral lengths and flow rates can be determined by using Figures in Appendix B. Linear tape laterals with various orifice spacings are shown. Not all types of Bi-Wall available are included. The inner diameter of all weights of Bi-Wall is 0.630 inches and will fit a standard 16mm insert fitting. Consult manufacturer's specifications for additional information. If linear tape laterals other than Bi-Wall are used, consult manufacturer's charts.

When selecting a linear tape lateral, note that a Bi-Wall 18" x 90" Bi-Wall lateral has a lower flow rate than 18" x 72" Bi-Wall. Unless a higher flow rate to match crop demand is required, the 18" x 90" Bi-Wall should be selected to obtain longer lateral runs within the allowable friction loss limitations.

### Example

A strawberry crop with a 1 ft x 4 ft spacing is grown in Abbotsford in a sandy loam soil. The trickle system design requirement has been calculated to be 0.27 G/P/D. The trickle system design parameters are:

| | |
|---|---|
| Plant spacing | 1 ft x 4 ft |
| Row Length | 400 ft (Field is considered to be flat.) |
| Number of rows | 250 |
| Irrigation Allotment | 50 gpm |

A trickle system uniformity of 80% is desired. The manufacturer's variance and an EU of 80% dictate a maximum pressure range of 15% of the emitter operating pressure. What linear tape lateral should be selected and what is the maximum lateral length? Also calculate the number of laterals per zone, the zone operating time and total system operating time.

A Bi-Wall 12" x 60" linear tape lateral is selected so that the orifice spacing matches the crop spacing.

For an operating pressure of 12 psi the maximum pressure range allowable throughout the zone is:

0.15 x 12 = 1.8 psi. Allowing 0.8 psi loss in the submain allows for a 1.0 psi loss in the lateral.

From Figure B.3 - the maximum lateral length for an operating pressure of 12 psi and a 1.0 psi loss along the lateral is: 275 ft

Since the row length is 400 ft the submain must bisect the row to incorporate the allowable lateral length. Two 200-foot laterals will therefore be required per crop row.

From Figure B.4 - the flow rate of a 200-ft. 12" x 60" lateral operating at 12 psi is 1.10 gpm.

The flow supplied per crop row is 2 x 1.10 gpm = 2.20 gpm/400 ft. row
= 132 gph/row

Water requirement per row = 0.27 G/P/D x 400 plants/row
= 108 gal/row/day

Operating time per zone $= \dfrac{\text{108 gal/row/day}}{\text{132 gal/hr/row}} = \text{0.82 hr/day}$

Number of rows/zone $= \dfrac{\text{Irrigation Allotment}}{\text{Water supplied per row}}$

$= \dfrac{\text{50 gpm}}{\text{2.2 gpm/row}}$

= 22 rows/zone

Number of zones $= \dfrac{\text{total number of rows}}{\text{number of rows/zone}} = \dfrac{250}{22}$

= 12 zones

Total system operating time = 12 zones x 0.82 hr/zone/day

= 9.8 hr/day.

**Note:** Figure 2.2, page 2-17 provides an example plan of a linear tape system design. A blank Trickle Irrigation Design Information Sheet is available in Appendix E.

## 2.4 SUBMAIN DESIGN

A submain or header line is required to evenly distribute water to a number of lateral lines. To maintain distribution, the pressure along the submain must remain relatively constant. As discussed in Section 2.3, the total pressure variation within a zone must include lateral friction losses, submain friction losses and elevation differences. The submain friction loss must therefore be accurately calculated.

### Single Size Submain Friction Loss Calculation

The friction loss in a submain with evenly spaced outlets is a fraction of the friction loss in the same submain with no outlets and the same flow rate. The value of this fraction depends on the number of outlets. Table 2.8 provides the fractional percentage of submain friction loss with numerous outlets.

Table 2.8 Submain Friction Loss Factors "F" for Multiple Outlets

| Number of Outlets | F | Number of Outlets | F |
|---|---|---|---|
| 1 | 1.0 | 16 | 0.365 |
| 2 | 0.625 | 17 | 0.363 |
| 3 | 0.518 | 18 | 0.361 |
| 4 | 0.469 | 19 | 0.360 |
| 5 | 0.440 | 20 | 0.359 |
| 6 | 0.421 | 22 | 0.357 |
| 7 | 0.408 | 24 | 0.355 |
| 8 | 0.398 | 26 | 0.353 |
| 9 | 0.391 | 28 | 0.351 |
| 10 | 0.385 | 30 | 0.350 |
| 11 | 0.380 | 35 | 0.347 |
| 12 | 0.376 | 40 | 0.345 |
| 13 | 0.373 | 50 | 0.343 |
| 14 | 0.370 | 100 | 0.338 |
| 15 | 0.367 |  | 0.333 |

From Hardie Design Manual

The most commonly used submain piping materials are polyethylene and PVC. Appendix C provides friction loss charts for the commonly used types and sizes of polyethylene and PVC pipe. Table 2.8 and the friction loss charts in Appendix C can be used to calculate friction loss for single sized submains.

#### Example 1a

A tree fruit crop in Kelowna has a 10 ft x 20 ft planting with a 400 ft row length. From example 1a on page 2-10 and 2-11 the following design parameters were obtained:

| | |
|---|---|
| Water supplied per row (lateral flow rate) | = 1.67 gpm/row |
| Number of rows per zone | = 50 rows/zone |

The zone flow rate (submain flow rate) is therefore:

$$1.67\ \frac{\text{gpm}}{\text{row}} \times 50\ \frac{\text{rows}}{\text{zone}} = 84\ \text{gpm/zone}$$

From example 1a on page 2-10 the following design parameters are obtained:

Lateral line specifications = 200 ft of 15 mm PE
Allowable zone friction loss = 3 psi
Lateral friction loss = 1.1 psi
Submain loss allowed = 1.9 psi

The submain must bisect the row since the 15 mm polyethylene only allows for 200 ft lateral lengths. (A flow rate of 1.67 gpm/row still results.)

From the above data the following submain information is calculated:

Submain length = 50 rows x 20 ft/row = 1000 ft
Number of outlets = 50

The allowable submain loss must include pipe friction loss as well as fitting loss. The fitting loss is usually approximated as 20% of the pipe friction loss.

The allowable submain loss of 1.9 psi in this example can therefore be separated as:

$$\begin{array}{lll} \text{Pipe friction loss} & & = \text{1.6 psi} \\ \text{Fitting loss} & = 0.2 \times 1.6 & = \underline{\text{0.3 psi}} \\ & & = \text{1.9 psi total} \end{array}$$

From Table 2.8 - for 50 outlets the "fraction factor" = 0.343

The allowable submain pipe friction loss of 1.6 psi for 50 outlets is therefore 34.3% of the pipe friction loss factor for one outlet. The pipe friction loss factor will therefore be:

$$\frac{1.6 \text{ psi}}{(1000 \text{ ft})(0.343)} = 0.0047 = \frac{0.47 \text{ psi}}{100 \text{ ft}}$$

From Table C.5 (Appendix C) - for a submain flow rate of 84 gpm and a pipe friction factor of $\frac{0.47 \text{ psi}}{100 \text{ ft}}$ a submain of 4" class 160 PVC would be required throughout. (In this case since 3" PVC is close it may be acceptable.)

The above example assumes that the submain feed is from one end. If the submain is fed in the center, the submain would be sized for a flow rate of 42 gpm and a pipe friction factor of 0.47 psi/100 ft. In this case, from Table C.5, 2 1/2" class 160 PVC could be used.

**It is important that the friction loss tables for the correct pipe type and size are used. If the pipe type used is not shown in this manual, obtain the friction data from the manufacturer.**

## Multiple Submain Pipe Size Friction Loss Calculation

The uniplot method shown in Appendix D can be used to design submains where more than one pipe size is to be used. For simple system designs table 2.9 can be used to determine submain size. An example illustrating the use of table 2.9 is given below.

### Example 1b

A tree fruit crop on a 10 ft x 20 ft planting and a 400 ft row length is grown in Kelowna. From example 1b on page 2-12 and 2-13 the following design parameters are obtained:

- water supplied per row = 6.4 gpm/row
- number of rows/zone = 14

- zone flow rate = 6.4 gpm/row x 14 rows = 90 gpm

From example 1b on page 2-15 the following design parameters are obtained:

- A microjet system with two 4.8 gph emitters installed per tree is to be used.

- A slope of 2% in the direction of the row planting exists for this example.

- Lateral line specifications = 400 ft of 26 mm PE

- Lateral friction loss = 3.12 psi

- Elevation gain along lateral = 400 ft x 0.02 = 8 ft = 3.5 psi

- Lateral pressure loss = 3.12 psi - 3.5 psi = -0.38 psi

- Allowable zone pressure loss = 3 psi
  = submain loss & lateral loss

- Allowable submain loss = 3 psi

In this case the allowable submain loss is equal to the allowable zone pressure variation as the lateral friction loss is negated due to the elevation drop along the lateral. To minimize pipe size the submain should be fed in the center. A sketch of the layout is shown in figure 2.3. The friction loss is calculated to match the allowable submain loss of 3 psi. For this example the submain should consist of 1", 1 1/4" and 1 1/2" class 160 PVC pipe.

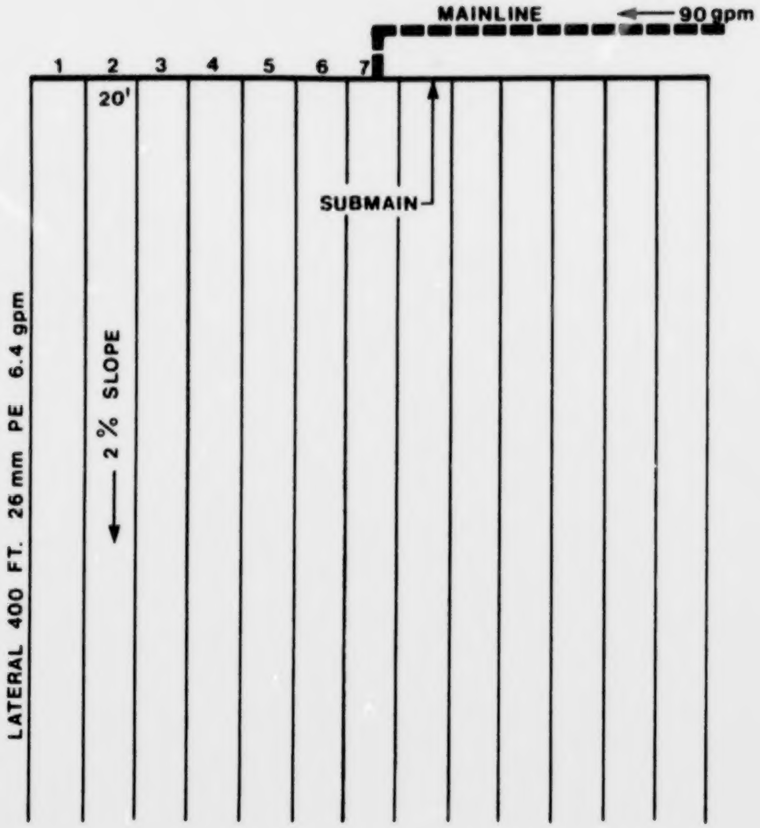


Figure 2.3 Sample Submain Layout

Using Table 2.9 the submain friction loss can be calculated as:

| Section | Flow (gpm) | Length of Pipe | Pipe Size | Friction Loss (psi) |
|---|---|---|---|---|
| 1 | 6.5 gpm | 20 ft | 1" | 0.12 |
| 2 | 13 | 20 | 1" | 0.41 |
| 3 | 19 | 20 | 1 1/4" | 0.25 |
| 4 | 26 | 20 | 1 1/4" | 0.45 |
| 5 | 32 | 20 | 1 1/2" | 0.34 |
| 6 | 38 | 20 | 1 1/2" | 0.46 |
| 7 | 45 | 10 | 1 1/2" | 0.32 |
| | | | | 2.40 psi |
| | Fitting Loss (Additional 20%) | | | 0.50 psi |
| | Total Submain Loss | | | 2.90 psi |

Table 2.9

## Submain Friction Loss
(Loss in psi for Class 160 PVC Pipe)

| SIZE (in) | FLOW (gpm) | LENGTH OF LINE (ft.) 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 |
|---|---|---|---|---|---|---|---|---|---|
| 1" | 1 | .001 | .002 | .003 | .004 | .005 | .006 | .008 | .01 |
| | 2 | .003 | .006 | .009 | .012 | .015 | .018 | .024 | .03 |
| | 3 | .01 | .02 | .02 | .03 | .04 | .04 | .06 | .07 |
| | 4 | .01 | .02 | .03 | .05 | .06 | .07 | .09 | .12 |
| | 5 | .02 | .04 | .05 | .07 | .09 | .10 | .14 | .18 |
| | 6 | .03 | .05 | .07 | .10 | .12 | .15 | .20 | .25 |
| | 7 | .03 | .07 | .10 | .13 | .17 | .20 | .26 | .33 |
| | 8 | .04 | .08 | .13 | .17 | .21 | .25 | .34 | .42 |
| | 9 | .05 | .11 | .16 | .21 | .26 | .32 | .42 | .52 |
| | 10 | .06 | .13 | .19 | .25 | .32 | .38 | .51 | .64 |
| | 11 | .08 | .15 | .23 | .30 | .38 | .46 | .61 | .76 |
| | 12 | .09 | .18 | .27 | .36 | .45 | .53 | .71 | .89 |
| | 13 | .10 | .21 | .31 | .41 | .52 | .62 | .83 | 1.04 |
| 1 1/4" | 10 | .02 | .04 | .06 | .08 | .10 | .12 | .15 | .19 |
| | 11 | .02 | .05 | .07 | .09 | .11 | .14 | .18 | .22 |
| | 12 | .03 | .05 | .08 | .11 | .13 | .16 | .21 | .27 |
| | 13 | .03 | .06 | .09 | .12 | .16 | .19 | .25 | .31 |
| | 14 | .04 | .07 | .11 | .14 | .18 | .21 | .28 | .36 |
| | 15 | .04 | .08 | .12 | .16 | .20 | .24 | .32 | .41 |
| | 16 | .05 | .09 | .14 | .18 | .23 | .27 | .36 | .45 |
| | 17 | .05 | .10 | .15 | .20 | .26 | .31 | .41 | .51 |
| | 18 | .06 | .11 | .17 | .23 | .28 | .34 | .45 | .57 |
| | 19 | .06 | .13 | .19 | .25 | .31 | .38 | .50 | .63 |
| | 20 | .07 | .14 | .21 | .27 | .34 | .41 | .55 | .69 |
| | 22 | .08 | .16 | .25 | .33 | .41 | .49 | .66 | .82 |
| | 24 | .10 | .19 | .29 | .38 | .48 | .58 | .77 | .96 |
| | 26 | .11 | .22 | .33 | .45 | .56 | .67 | .89 | 1.12 |
| | 28 | .13 | .26 | .38 | .51 | .64 | .77 | 1.02 | 1.28 |
| | 30 | .15 | .29 | .44 | .58 | .73 | .87 | 1.16 | 1.46 |

Table 2.9

## Submain Friction Loss
(Loss in psi for class 160 PVC pipe)

| SIZE | FLOW | LENGTH OF LINE (ft.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| (in) | (gpm) | 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 |
| 1 1/2" | 14 | .02 | .04 | .06 | .07 | .09 | .11 | .15 | .19 |
| | 16 | .02 | .05 | .07 | .09 | .12 | .14 | .19 | .24 |
| | 18 | .03 | .06 | .09 | .12 | .15 | .17 | .23 | .29 |
| | 20 | .04 | .07 | .11 | .14 | .18 | .21 | .28 | .36 |
| | 22 | .04 | .09 | .13 | .17 | .21 | .26 | .34 | .43 |
| | 24 | .05 | .10 | .15 | .20 | .25 | .30 | .40 | .50 |
| | 26 | .06 | .12 | .17 | .23 | .29 | .35 | .46 | .58 |
| | 28 | .07 | .13 | .20 | .26 | .33 | .40 | .53 | .66 |
| | 30 | .08 | .15 | .23 | .30 | .38 | .45 | .60 | .75 |
| | 32 | .09 | .17 | .26 | .34 | .43 | .51 | .68 | .85 |
| | 34 | .10 | .19 | .29 | .38 | .48 | .57 | .76 | .95 |
| | 36 | .11 | .21 | .32 | .42 | .53 | .63 | .85 | 1.06 |
| | 38 | .12 | .24 | .35 | .46 | .58 | .70 | .93 | 1.17 |
| | 40 | .13 | .26 | .38 | .51 | .64 | .77 | 1.02 | 1.28 |
| | 45 | .16 | .32 | .48 | .64 | .80 | .96 | 1.40 | 1.60 |
| 2" | 20 | .01 | .02 | .04 | .05 | .06 | .07 | .10 | .12 |
| | 22 | .02 | .03 | .04 | .06 | .07 | .09 | .12 | .15 |
| | 24 | .02 | .03 | .05 | .07 | .09 | .10 | .14 | .17 |
| | 26 | .02 | .04 | .06 | .08 | .10 | .12 | .16 | .20 |
| | 28 | .02 | .05 | .07 | .09 | .11 | .14 | .18 | .23 |
| | 30 | .03 | .05 | .08 | .10 | .13 | .15 | .20 | .26 |
| | 35 | .03 | .07 | .10 | .14 | .17 | .20 | .27 | .34 |
| | 40 | .04 | .09 | .13 | .17 | .22 | .26 | .34 | .43 |
| | 45 | .05 | .10 | .16 | .22 | .27 | .32 | .43 | .54 |
| | 50 | .07 | .13 | .20 | .26 | .33 | .39 | .52 | .66 |
| | 55 | .08 | .16 | .23 | .31 | .39 | .47 | .62 | .78 |
| | 60 | .09 | .18 | .27 | .37 | .46 | .55 | .73 | .92 |

# III GREENHOUSE TRICKLE IRRIGATION SYSTEM DESIGN

The greenhouse systems discussed in this chapter are controlled environment systems. The design and selection of a greenhouse irrigation system is dependent to some extent on the type of greenhouse structure. Structure designs which limit air infiltration have an effect on the amount of moisture retained in the greenhouse. "Tighter" greenhouses will have higher humidity levels. This could lead to the following undesirable results:

- increased dampness inside the greenhouse which may induce weed, insect, and disease problems.
- water condensation inside the greenhouse may reduce light levels which could lower production.
- condensate dripping from the roof could damage ornamental foliage.

To overcome the humidity problems, increased ventilation and heating are often used. The problem can also be overcome by limiting the amount of water entering the greenhouse. The most efficient irrigation system would deliver exactly the amount of water required for optimum plant growth. Any excess water delivered into the greenhouse will:

- increase ventilation needs
- absorb energy to heat this additional water

Trickle irrigation systems are an efficient method of applying water to container grown greenhouse crops. This Chapter provides information on designing a trickle system to meet the maximum greenhouse crop water demand.

## 3.1 GREENHOUSE CROP WATER REQUIREMENTS

The moisture requirement of a greenhouse crop will depend on the type of soil or soil mixture and the size of the container or bed. The watering requirement should allow at least 10% for leaching of salts and to provide good fertilizer distribution. Table 3.1 provides estimates of the maximum daily water requirements for various crops and planting schemes.

### Scheduling Irrigation Applications

Deciding on an irrigation schedule for greenhouse crops will be dependent on:

- the crop water requirement for the crop growth stage, light intensity, and temperature conditions that exist.
- the number of emitters per plant
- the container size
- the type of soil mix or culture used

If a free draining non soil culture is used, the crop can be watered 2-3 times per hr. Any excess water applied will drain within 10 minutes of saturation to provide a good air-water balance in the growing media for optimum root growth. Frequent watering will be required as the moisture holding capacity of these mediums is very limited.

If using a soil mix that is not freely drained care must be taken not to apply too often, as waterlogging may result in crown or root rot.

Table 3.1 Greenhouse Crop Maximum Daily Water Requirements

| Crop | Crop Density | Water Requirement |
|---|---|---|
| Cucumber | 1.0 - 1.4 plants/10 $ft^2$ sawdust culture | 1.0 - 1.5 gal/plant/day |
| Tomatoes | beds | 0.25 gal/$ft^2$ of bed area |
|  | 1.0 plant/5 $ft^2$ (sawdust culture) | 0.75 gal/plant/day |
| Bench Crops |  | 0.4 gal/$ft^2$ |
| Bedding Plants |  | 0.5 gal/$ft^2$ |
| Pot Plants |  | 0.5 gal/$ft^2$ |
| Chrysanthemums<br>Hydrangea |  | 1.5 gal/$ft^2$ |
| Roses |  | 0.7 gal/$ft^2$ of bed area |

**Cucumber**

Upon planting out, place the emitters at the edge of the root ball. Allow three drippers per plant if sand is not used in the bags. Keep the emitter away from the plant stem to reduce the potential of crown rot.

For sawdust culture, irrigation application should be timed in conjunction with fertilizer feeding. During the day, hourly or 1/2 hourly applications of feeding can be given. Allow 10 - 20% leaching to ensure soluble salt accumulation does not occur. Leaching requirements up to 30% may be necessary depending on water quality. Start by applying 0.25 gal (1000 mL) per day and increase feeding volumes as sunlight and plant size increase. A mature plant will require 1.0 - 1.75 gallons (4-7 liters) per day. Feeding once or twice during the night reduces plant stress and may also be beneficial.

The B.C. Ministry of Agriculture and Food Greenhouse Cucumber and Tomato Production Guide provides information on basic feeding formulas for greenhouse cucumber crops.

### Tomato

Tomato plants grown in sawdust culture will require watering at least once per hour in bright sunlight. More frequent waterings may be beneficial - up to six times per hour during peak conditions for mature plants.

Feed volumes for tomatoes will start at 0.10 gallons (400 mL)/plant/day and increasing to 0.75 gallons (3000 mL)/plant/day. The peak use rate for tomatoes grown in greenhouses is 0.15 - 0.20 gal/hr (0.5 - 0.75 L/hr.)

## 3.2 GREENHOUSE TRICKLE SYSTEM DESIGN CRITERIA

### Emitter Selection

To calculate the proper line sizing, zone control and pump requirements an emitter flow rate and the number of emitters per bag must first be selected.

For soilless culture, there are usually 2 or 3 emitters installed per bag. A soil mix medium may require 1 or 2 emitters per planting pot. Generally emitter discharge rates of 1/2 - 2 gal/hr (2 - 8 L/hr) are selected. There are two basic emitter types that are recommended, microtubes and point source emitters using a microtube for transfer tubing. Figure 5.10 on page 5-9 indicates the different type of installation methods.

If a microtube system is selected, the flow rate from the tubing is determined by the operating pressure and tubing length. Flows from 0.045 I.D. and 0.060 I.D. tubing can be determined from Figures 3.1 and 3.2. To obtain the desired flow rate from a microtube system, excessively long lengths of tubing may be required to reduce pressure.

Another method often used to achieve lower flow rates is to use a point source emitter to regulate the flow and use 0.060 microtubing to transfer the water from the lateral to the plant's pot or growing medium. The amount of microtubing required with this method can be greatly reduced.

### Lateral and Header Line Sizing

Since greenhouse systems also use the trickle irrigation system for nutrient feeding every irrigation, it is imperative that good uniformity is obtained. The header and lateral lines must therefore be sized to ensure that water is distributed evenly throughout the entire greenhouse. A coefficient of uniformity of 90% or better should be obtained. The maximum pressure variation in a zone should not exceed 10% of the emitter operating pressure in a zone. See Sections 2.3, 2.4 and Chapter 4 for further information on system uniformity. It is important to keep lateral sizes as small as possible while maintaining uniformity. This can be done by keeping laterals short. Since greenhouse trickle systems are operated frequently but for short durations, the fill time requirements as well as lateral seepage during shutdown must be minimized to achieve good uniformity of application.

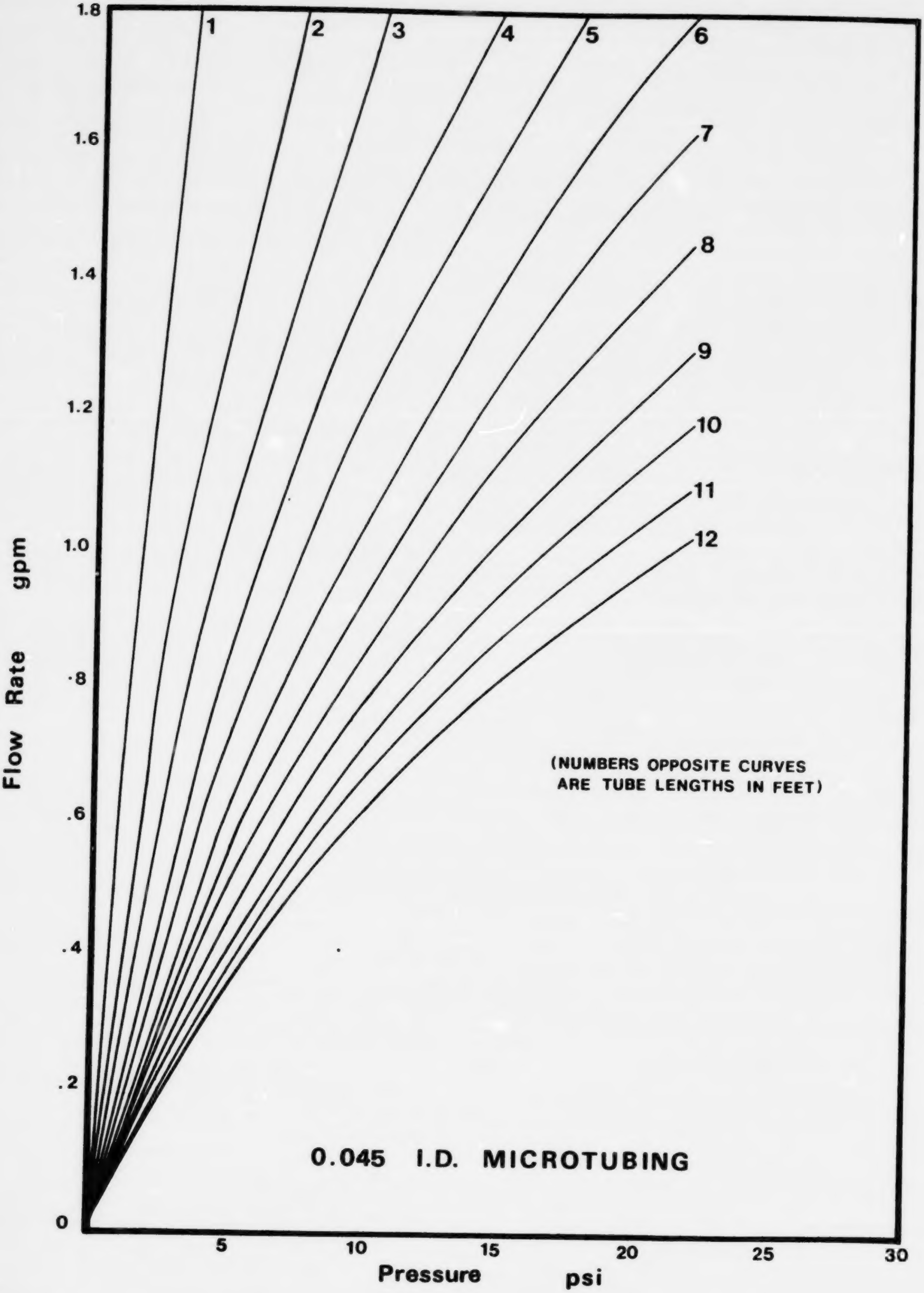


Figure 3.1 (0.045 I.D. Microtube Flow Chart)

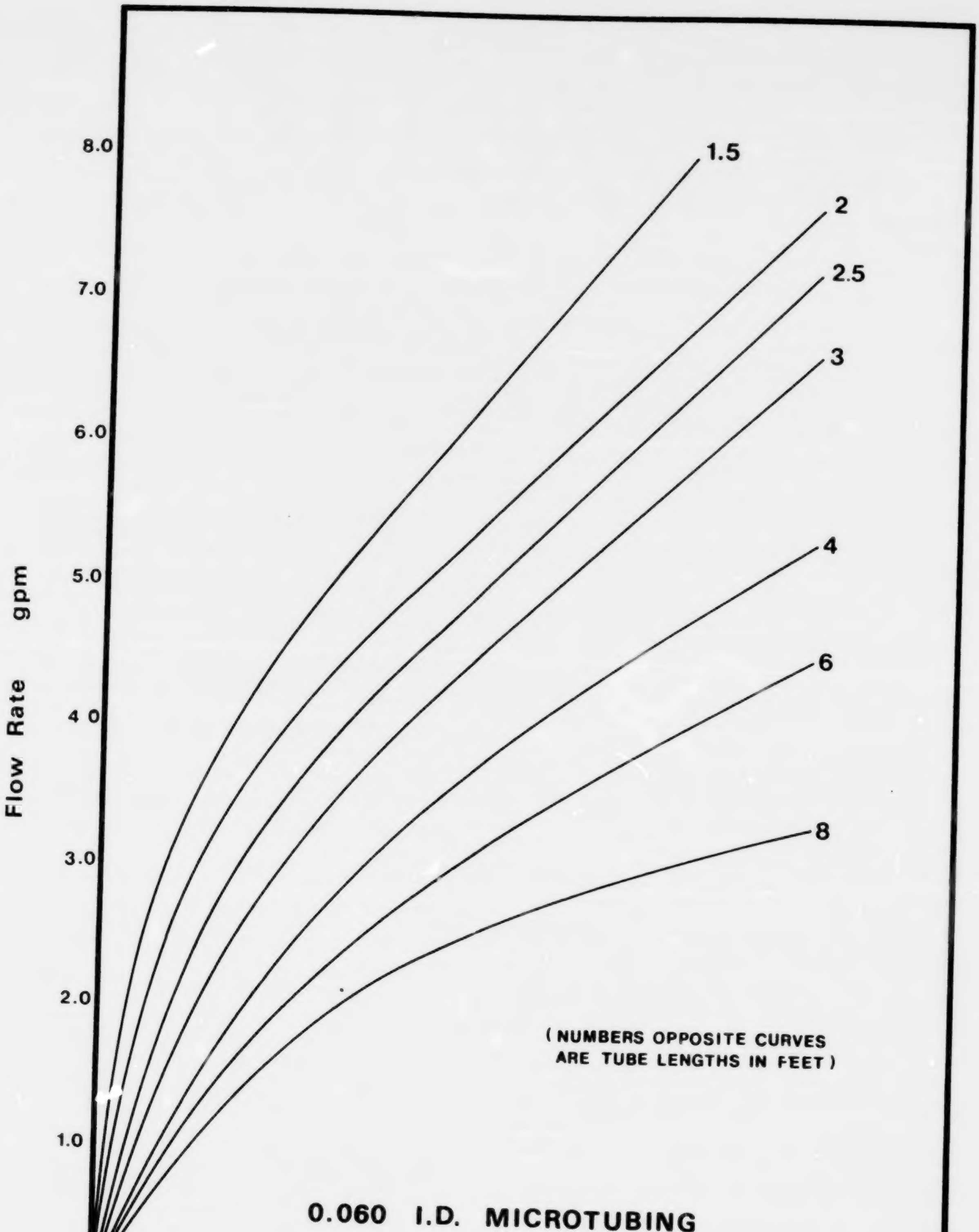


Figure 3.2 0.060 I.D. Microtube Flow Chart

## Example: Greenhouse Layout and Sample Design

A tomato grower has a greenhouse 150 ft x 250 ft which houses 7,500 tomato plants. The plants are grown in sawdust filled bags spaced in double rows 24" off center. The rows are spaced 5.0 ft apart. There is a 10 ft center panel down the middle of the greenhouse. See Figure 3.3 for system layout.

The crop density for the greenhouse is $\frac{150\text{ ft} \times 250\text{ ft}}{7{,}500\text{ plants}} = 5\text{ ft}^2/\text{plant}$

From Table 3.1 the maximum daily crop water requirement is 0.75 gal/plant/day.

The system manager determines that the peak crop use rate will be 0.2 gal/hr. Two emitters will be installed per plant, with flow rates of 0.5 gph each. The plants are to receive 0.05 gallons per watering, with 4 waterings per hour.

### Storage Sizing

The bulk storage and fertilizing mixing tank should be capable of storing at least one day of water supply. Normally, a two day water storage is selected.

The storage tank size for two days storage will be:

7,500 plants x 0.75 gal/plant/day x 2 days = 11,250 gallons = 1504 $\text{ft}^3$

If a concrete tank is used the storage facility must be at least
18ft x 10.5ft x 8ft deep.

### Zone Sizing

The on time for each zone per watering will be:

$$\frac{0.05\text{ gal/watering}}{2 \times 0.5\text{ gph/emitter}} = 0.05\text{ hrs}$$

The on time for each zone per hour will be:

$$0.05\text{ hrs/watering} \times 4\text{ waterings} = 0.2\text{ hrs} = 12\text{ min}$$

$$\text{The maximum number of zones} = \frac{60\text{ min/hr}}{\text{operating time per zone per hour}}$$

$$= \frac{60\text{ minutes/hr}}{12\text{ minutes/zone}} = 5\text{ zones}$$

To allow flexibility in operation the greenhouse should be divided into no more than 4 zones.

$$\text{Number of plants per zone} = \frac{7500}{4} = 1875$$

$$\text{Flow rate per zone} = 1875\text{ plants} \times \frac{2\text{ emitters}}{\text{plant}} \times \frac{0.5\text{ gph}}{\text{emitter}} = 1875\text{ gph}$$

$$= 31.3\text{ gpm/zone}$$

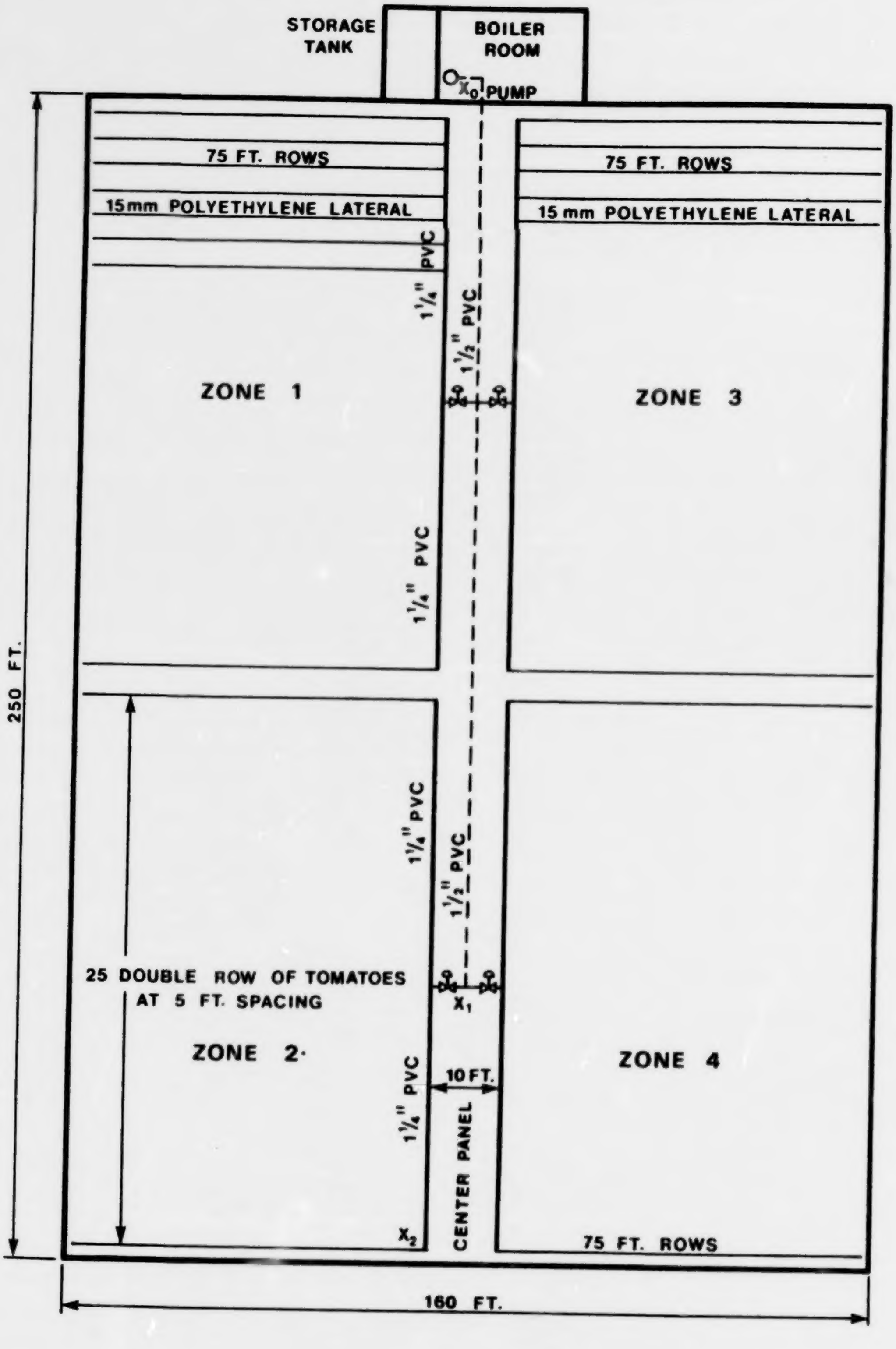


Figure 3.3 Sample Greenhouse System Layout

The above calculations indicate that a system designed with four zones , two emitters per plant, will be capable of providing the maximim hourly water requirement desired of 0.2 gal/plant. Note that the peak use of 0.2 gal/plant for four hours will exceed the maximum anticipated daily plant water requirement of 0.75 gal/plant. It is the responsibility of the system manager to ensure that the daily water requirement is delivered as required by the plant throughout the day.

**Lateral Sizing**

The emitter selected will provide 0.5 gal/hr at 15 psi pressure. The maximum pressure variation should not exceed 1.5 psi in the lateral and header line. It is important that the lateral piping is also kept as small as possible to reduce filling time upon start up. The length of each lateral line in this example is 75 ft.

To allow for friction loss in the header line the maximum allowable friction loss in the lateral will be 0.8 psi.

Flow rate per foot in the lateral

$$= \frac{\text{2 emitters/plant} \times \text{0.5 gph/emitter}}{\text{1 ft plant spacing}} = \text{1.0 gph/ft}$$

From Figure A.3 - 75 ft of 15 mm I.D. polyethylene at a flow rate of 1.0 gph/ft has a friction loss of 1.25 ft = 0.54 psi

- allowing 30% for emitter barb loss = 0.16 psi

Total lateral loss = 0.7 psi

**Header Line Sizing**

As shown in Figure 3.3, the section of the header line which will affect the pressure uniformity throughout the zone is the portion which runs from the control valve to the last lateral ($X_1$-$X_2$). The allowable friction loss in this section will be:

maximum pressure variation within the zone - lateral friction loss

= 1.5 psi - 0.7 psi = 0.8 psi

The total flow rate for each zone is 31.3 gpm. The header line section from the zone control valve to the last lateral ($X_1$-$X_2$) has a flow rate of 15.7 gpm.

From section 2.4, page 2-20 the friction loss can be calculated using a single size submain.

The allowable header friction loss is 0.8 psi. Including 20% for fitting loss, the header line friction loss can therefore be separated as:

| | | |
|---|---|---|
| Pipe friction loss | = | 0.66 psi |
| Fitting loss = 0.2 x 0.66 | = | 0.14 psi |
| | | 0.80 psi |

From Table 2.8 a friction loss factor of 0.373 is selected for 13 outlets.

The header line pipe friction loss of 0.66 psi for 13 outlets is therefore 37.3% of the pipe friction factor for one outlet. The submain length is 13 rows x 5 ft/row = 65 ft.

The pipe friction loss factor is therefore:

$$\frac{0.66\text{ psi}}{65\text{ ft} \times (0.373)} = \frac{0.027\text{ psi}}{\text{ft}} = \frac{2.7\text{ psi}}{100\text{ ft}}$$

From Table C.4 (Appendix C)

For section $X_1 - X_2$ with a flow rate of 15.7 gpm and a pipe friction loss factor of 2.7 psi/100 ft a 1 1/4" Class 125 PVC pipe is required throughout.

The actual friction loss for section $X_1 - X_2$ with a 1 1/4" PVC header line is:

From Table C.4

1 1/4" Class 125 PVC @ 15.7 gpm = 0.86 psi/100 ft

For a 65 ft line with 13 outlets the friction loss is

$$65\text{ ft} \times 0.373 \times \frac{0.86\text{ psi}}{100\text{ ft}} = 0.21\text{ psi}$$

Fitting loss = 20% of pipe loss = 0.20 x 0.21 = 0.04 psi

Total header loss = 0.25 psi

The pressure setting at the zone control valve will be:

| | | |
|---|---|---|
| Emitter operating pressure | = | 15.0 psi |
| Lateral loss | = | 0.7 psi |
| Header loss | = | 0.25 psi |
| Pressure setting at zone control valve | = | 16.0 psi |

**Mainline Sizing**

The mainline from the boiler room to the zone control valves ($X_0$-$X_1$) must supply 31.3 gpm. The mainline length is 200 ft. The mainline should be sized so that flow velocities do not exceed 5 ft/sec (See section 6.1 for information on mainline sizing.

From Table C.4

For a flow rate of 31.3 gpm a mainline size of 1 1/2" class 125 PVVC is selected.

1 1/2" class 125 PVC pipe @ 31 gpm has a friction loss of

$$\frac{1.5 \text{ psi}}{100 \text{ ft}} \text{ (by interpreting the table)}$$

$$200 \text{ ft} \times \frac{1.5 \text{ psi}}{100 \text{ ft}} = 3.0 \text{ psi}$$

There is a 3 psi loss due to pipe friction in the 200 ft class 125 PVC mainline.

See Chapter 6 for information regarding pump sizing. The pump must be sized to allow enough pressure to overcome all friction loss and pressure requirements, including values, monitoring equipment, etc. Accurate determination of valve friction loss is important when the system operating pressures are very low.

# IV EMITTER DATA

An emitter is a device which utilizes a long flow path or an orifice for pressure dissipation to obtain a low flow rate. The operating pressure of a trickle irrigation system is normally between 8 and 25 psi. The purpose of the emitter is to reduce the line pressure to allow for a slow discharge rate. The method used for pressure reduction will vary with emitter type. A few pressure reducing principles are explained in the following section.

## 4.1 EMITTER PRESSURE REDUCING PRINCIPLES

### Laminar Flow Emitters

A laminar flow condition is when fluid particles move in a slow organized fashion at a low velocity. Laminar flow emitters regulate discharge by using friction to dissipate energy. Longer or smaller flow passages increase the frictional resistance to the flow of water, thereby reducing the emitter discharge rate. Laminar flow emitters usually have long and narrow flow paths. Microtube and spiral flow path emitters are good examples of laminar flow emitters. (See F and G of Figure 4.1).

Laminar flow emitters are simple, reliable and inexpensive providing they are installed properly. Due to the slow water velocity and narrow passages, laminar flow emitters are susceptible to plugging. Good water quality must be maintained by adequate filtration, chemical treatment if necessary and line flushing.

Laminar flow emitters are also sensitive to pressure fluctuation and water viscosity. (Flow rates will vary with pressure changes and water temperature. See Section 4.2).

### Turbulent Flow Emitters

A turbulent flow condition is when fluid particles move in a random, disorganized motion. Turbulent flow emitters regulate discharge by fluid friction with the emitter walls and passages as well as between the fluid particles. Orifiçe emitters and linear tape systems that use orifices are examples of turbulent flow emitters. (See A, C, D and L of Figure 4.1).

Compared to a laminar flow emitter, a turbulent flow emitter has the following advantages:

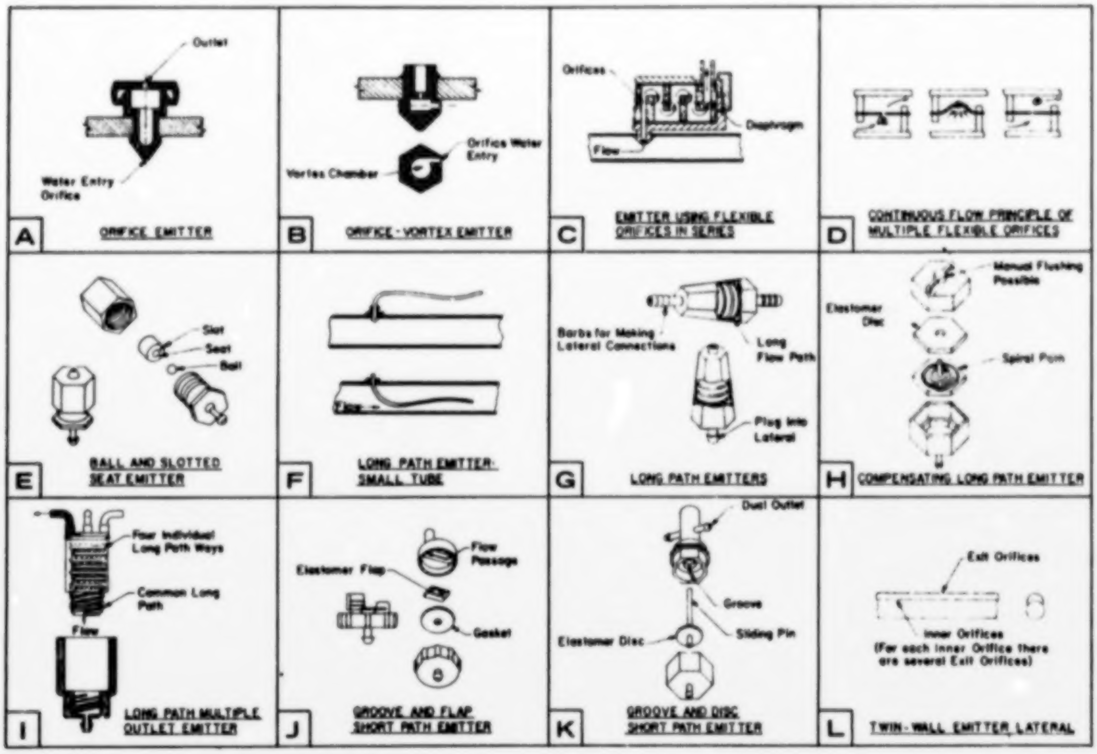
- shorter and larger flow paths
- higher water flow velocities
- less sensitive to pressure fluctuations
- flow rate is unaffected by water temperature changes

When selecting an emitter it is important to realize whether an emitter is fully turbulent or only partially turbulent flow. Although turbulent flow emitters are less susceptible to pressure fluctuations than laminar flow emitters, they should not be used as pressure compensating emitters.

## Vortex Emitters

Vortex emitters use the principle that a reduced pressure exists at the center of a vortex. The emitter outlet is located at the center of the vortex chamber. Centrifugal force pushes water towards the center where the discharge rate is reduced due to the lower pressure condition. (See B, Figure 4.1).

A true vortex emitter is less pressure sensitive than a turbulent flow emitter. Since a vortex emitter utilizes only a single orifice good quality filtration is required to ensure that clogging isn't a problem.


Outlet
Water Entry Orifice
A
ORIFICE EMITTER
Orifice Water Entry
Vortex Chamber
B
ORIFICE - VORTEX EMITTER
Orifices
Diaphragm
Flow
C
EMITTER USING FLEXIBLE ORIFICES IN SERIES
D
CONTINUOUS FLOW PRINCIPLE OF MULTIPLE FLEXIBLE ORIFICES
Slot
Seat
Ball
E
BALL AND SLOTTED SEAT EMITTER
Flow
F
LONG PATH EMITTER: SMALL TUBE
Barbs for Making Lateral Connections
Long Flow Path
Plug into Lateral
G
LONG PATH EMITTERS
Manual Flushing Possible
Elastomer Disc
Spiral Path
H
COMPENSATING LONG PATH EMITTER
Four Individual Long Path Ways
Common Long Path
Flow
I
LONG PATH MULTIPLE OUTLET EMITTER
Flow Passage
Elastomer Flap
Gasket
J
GROOVE AND FLAP SHORT PATH EMITTER
Dual Outlet
Groove
Sliding Pin
Elastomer Disc
K
GROOVE AND DISC SHORT PATH EMITTER
Exit Orifices
Inner Orifices
(For each Inner Orifice there are several Exit Orifices)
L
TWIN-WALL EMITTER LATERAL

from K. Solomon, Rainbird Sprinkler Mfg. Corp.

Figure 4.1 Trickle Irrigation Emitter Types

### Pressure Compensating Emitters

Pressure compensating emitters can be either turbulent or laminar flow. A pressure compensating emitter utilizes the inlet pressure to modify the flow passage. This modification is accomplished by exerting pressure on an elastomeric disc, diaphragm or the water passage. An increase in pressure will reduce the flow passage. (See H, Figure 4.1). Pressure compensating emitters are therefore able to operate over a pressure range of 15-40 psi while maintaining the flow rate relatively constant. Pressure compensating emitters are relatively expensive and should therefore only be used where absolutely necessary, for example in undulating terrain.

## 4.2 EMITTER CLASSIFICATION

Various types of emitter devices are shown in Figure 4.1 Although the method of pressure reduction may vary, emitters can be classified into three separate categories.

### Linear Tape System

There are two types of linear tape systems, the weeping or porous wall type and the orifice type. The weeping or porous wall type is made up of a plastic which contains micropores throughout its entire length. The water slowly oozes out of these micropores. Good filtration and algae control is required to make this type of system functional.

Linear tape systems also use orifices spaced at regular intervals to supply water to row crops. These types of systems are available in both single wall and double wall construction. In the case of twin wall or double wall systems, two sets of orifices are used. The main chamber acts as a lateral and distributes water to the outer chamber through the inner orifices. Water is distributed to the crop by means of the exit orifices in the outer chamber. A Bi-Wall notation of 18" x 90" indicates that the outer orifices are spaced at 18" while the inner orifices are spaced 90 in. apart (See L, Figure 4.1). Linear tape systems normally discharge between 30 gph - 60 gph per 200 feet of length, depending on the spacing of the exit orifice. **See Appendix B for linear tape flow charts.** Normal operating pressures for linear tape systems is between 8 - 14 psi.

These types of systems are normally used for row crops such as tomatoes, strawberries and vegetables. Lateral water movement in the soil from these types of systems is similar to point source emitter systems. (See Table 4.1.)

## Point Source Emitter System

A point source emitter is a device which emits water at a specified rate to a localized area of the plant root zone. The operating characteristics of point source emitters range from 0.5 gph - 2.0 gph at operating pressures ranging from 10-20 psi.

There are various types of point source emitters including in-line, barbed and clip-on emitters. A linear tape system with orifices at specified intervals also functions as a point source emitter. Linear tape and point source emitter systems rely on the combined forces of gravity and capillarity to move water laterally and downward through the root zone.

It is important that enough orifices, appropriately spaced, are provided for plants with extensive root zones.

Selecting the number of emitters required per plant will be dependent upon the plant root volume, rooting depth and the lateral spread of water. When converting from a sprinkler irrigation to a trickle irrigation system at least 40% of the existing root volume must be wetted. The same criteria should be used when designing a trickle system for newly planted crops. Enough emitters must be installed so that an adequate root system develops. If not, the crop may suffer during peak conditions. Perennial crops with underdeveloped root systems may tip or fall over as the plant matures.

To increase lateral movement of water in sandy soils requires a slow application of water at low flow rates. Even so, sandy soils tend to have deep, narrow wetted patterns. Conversely, heavy soils require higher rates of application to increase downward water movement by soil saturation. Care should be taken to ensure that heavy soils do not become waterlogged.

The amount of lateral movement achievable will be determined by the rate of application, duration of application and plant rooting depth. (There is no point in applying water below the plant root zone). Shallow rooted crops with wide spread root zones require closer emitter spacings to ensure that enough of the root volume is watered. Spray emitter systems should be considered for these types of situations.

The values of lateral water movement in Table 4.1 are maximum values assuming deep rooted crops as well as the right combination of application rate and duration. The designer may have to adjust emitter spacings for other conditions.

Figure 4.2 graphically depicts water movement under point source emitter systems. Note the effect that a soil boundary or a hardpan layer will have on the wetted zone.

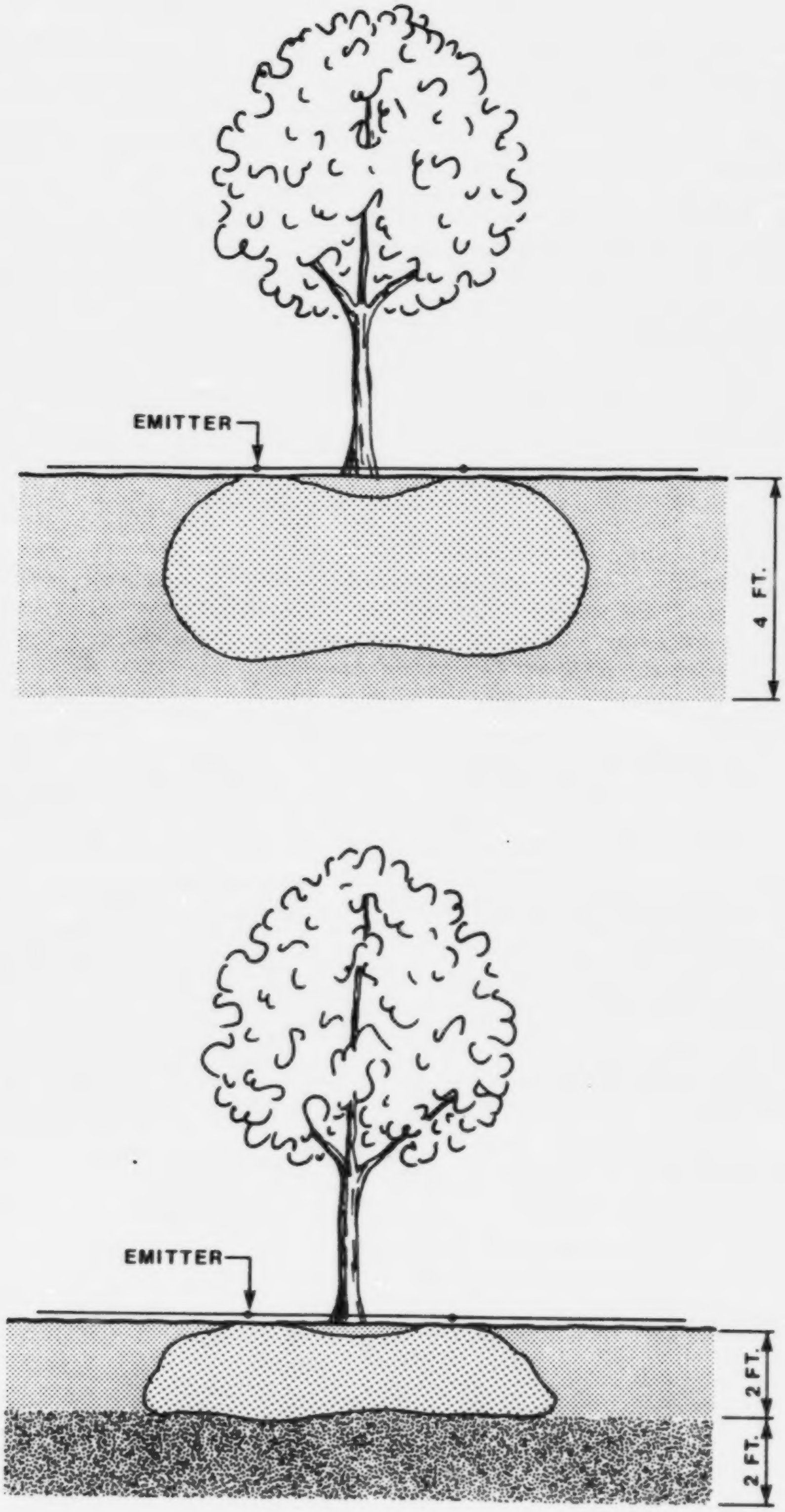


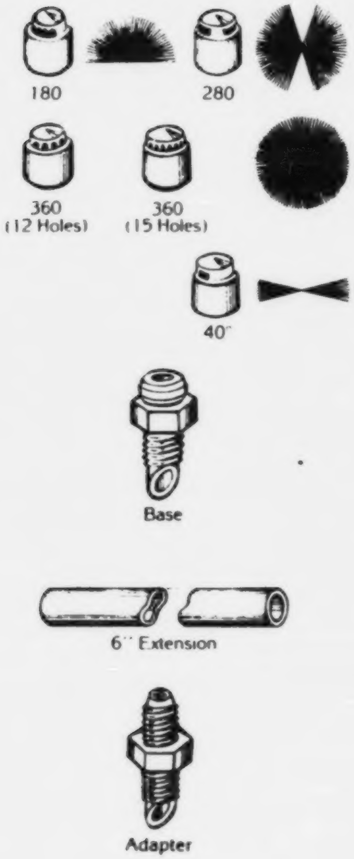
Figure 4.2 Soil Water Movement from Point Sources

**Table 4.1 Lateral Water Movement in Soils from Point Source Emitters**

| Soil Type | Lateral Spread (Diameter in Feet) |
|---|---|
| Coarse soils, shallow, stony | 4.0 ft. |
| Fine soils, shallow, stony | 5.0 ft. |
| Loamy sand, deep | 5.0 ft. |
| Sandy loam, loam, deep | 7.0 ft. |
| Silt, silt loam, deep | 6.0 ft. |

## Spray Emitter Systems

Spray emitters use a wetted diameter to distribute water throughout the plant root zone. If operated long enough, lateral movement of water will also occur. Spray emitters discharge from 4-50 gph at operating pressures ranging from 10 to 25 psi. Spray emitters have higher flow rates than point source emitters which make them less susceptible to clogging. However, the spray emitter orifice sizes used in the trickle irrigation industry require at least a good quality screen mesh filtration system. The smaller jet orifices are usually used (.03, .04 inch) so that standard lateral line sizes will accommodate the required flow rate. Spray emitter specifications are shown in Table 4.2.



Spray Top
Diameter of throw - 5 ft for small orifice at low pressure
- 19 ft for larger orifice orifice at higher pressure

Base - Regulates flow rate
Flow rates range from 4 to 48 gph
Operating pressure range 10-25 psi

Extension - can be installed to any length

Adapter - plugs into lateral line

Figure 4.3 Spray Emitter Components

Table 4.2 **Spray Emitter Specifications**

| Orifice Diameter | Pressure (psi) | Discharge (gph) | Spray Pattern | | | |
|---|---|---|---|---|---|---|
| | | | 40° Dia (ft) | 180° Rad (ft) | 280° Dia (ft) | 360° Dia (ft) |
| .03" | 10 | 4.1 | 4.8 | 4.6 | 7.9 | 7.4 |
| | 15 | 4.8 | 6.8 | 5.3 | 8.9 | 8.8 |
| | 20 | 5.7 | 8.4 | 5.9 | 9.9 | 10.4 |
| | 25 | 6.6 | 10.0 | 6.6 | 10.3 | 11.0 |
| .04" | 10 | 8.0 | 6.8 | 5.5 | 8.0 | 8.2 |
| | 15 | 9.0 | 10.5 | 5.9 | 9.9 | 9.5 |
| | 20 | 10.0 | 12.6 | 6.7 | 11.7 | 11.2 |
| | 25 | 11.3 | 14.8 | 7.1 | 14.0 | 13.3 |
| .05" | 10 | 10.5 | 7.9 | 6.1 | 10.2 | 11.0 |
| | 15 | 13.0 | 11.6 | 6.6 | 11.5 | 12.6 |
| | 20 | 14.8 | 15.7 | 8.1 | 12.3 | 14.5 |
| | 25 | 16.5 | 17.6 | 8.5 | 13.0 | 16.2 |
| .06" | 10 | 15.9 | 8.9 | 6.0 | 10.5 | 12.3 |
| | 15 | 19.5 | 13.0 | 7.2 | 12.1 | 14.9 |
| | 20 | 22.9 | 17.1 | 8.5 | 14.3 | 17.9 |
| | 25 | 25.9 | 19.6 | 9.0 | 15.1 | 19.3 |
| .07" | 10 | 30.0 | 9.5 | 6.4 | 12.0 | 11.0 |
| | 15 | 37.5 | 15.4 | 7.6 | 13.6 | 13.8 |
| | 20 | 43.4 | 19.3 | 8.2 | 15.8 | 15.5 |
| | 25 | 47.9 | 21.9 | 9.2 | 16.8 | 19.3 |

From Microjet Corp., Florida.

## 4.3 EMITTER SELECTION

The decisions required in the selection of an efficient emitter will include:

1) Type of crop - An emitter must be selected to match the type of crop. The emitter discharge rate and placement is related to crop spacing and water requirement. The emitters must be capable of supplying peak water requirements as well as wet an adequate portion of the plant root zone.

2) Water Quality - The type of emitter selected dictates the filtration requirements necessary. In areas of very poor water quality it may be beneficial to select an emitter that doesn't clog easily, thereby reducing the filtration requirements.

3) Farm Management - Crop harvesting methods, tillage, cover crop control and other cultural practices determine which type of emitter should be used. The emitter system must be durable enough to withstand any physical abuse from various farming operations. (e.g. Mechanical harvesting).

4) System Installation - Trickle systems can be suspended in the crop, laid on the ground or buried. If the system is to be buried the emitter must be guaranteed to operate for at least the crop duration. Buried systems are not easily checked, with plant conditions and response being the major indicator of a plugged system. Use of flow meters should be considered manditory for these type of installations.

5) Operating Characteristics - It is recommended that any particular zone does not operate for more than 12 hours per day. A trickle irrigation system should be operated on an intermittent basis to reduce algae growth and allow air movement into the soil. The peak water requirements must therefore be supplied in 12 hours or less.

6) Cost - A trickle system may use between 500 to 1000 emitters per acre. The cost of the emitter is therefore a significant portion of the overall system cost.

7) Topography - To maintain a good trickle irrigation system uniformity a turbulent flow or pressure compensating emitter may be required due to elevation variances throughout the system. See Section 4.4.

8) Manufacturer's Variance Coefficient - Flow rate variations will occur due to manufacturing variances in emitter construction. The manufacturer's variance should be determined and analyzed to ensure that the resulting flow variations will not severely effect system uniformities. See section 4.4.

## 4.4 TRICKLE IRRIGATION SYSTEM UNIFORMITY

Material and data for this section are referenced from Michael Boswell, Hardie Irrigation Manual.

A trickle irrigation system must be designed to an application uniformity of 90%. The emitter discharge rates throughout the entire trickle system must therefore be limited to a 10% variation in flow. The variables that affect the emitter discharge rate are pressure, temperature and emitter characteristics. The temperature effects on emitter flow rates and pressure effects on trickle system uniformites are covered in this section.

### Emitter Flow Rate Correction for Temperature

Most emitters regulate flow by disposing of energy through frictional resistance. The flow rate of an emitter can therefore be calculated from the formula:

$$Q = Kd\ (H)^{x}$$

where $Q$ = Flow Rate (gph)
$H$ = operating pressure (psi)
$Kd$ = flow coefficient
$x$ = flow exponent

The flow coefficient Kd is related to the physical dimensions of the flow passage. The flow exponent x depends upon whether the emitter flow is vortical, fully turbulent, fully laminar or between turbulent and laminar. The uniformity of application is effected by the flow exponent x. The lower the x value, the more pressure compensating the emitter is. A fully pressure compensating emitter will have an x value of 0. An emitter that is very pressure sensitive, or fully laminar flow, will have an x value of 1.0. Table 4.3 graphically shows the flow exponent x in relation to emitter types.

Table 4.3 Flow Exponent Values for Various Flow Regimes and Emitter Types

| Flow Regime | x Value | Emitter Type |
|---|---|---|
| Variable Flow Path | 0.0 | Pressure Compensating Emitter |
| | 0.1 | |
| | 0.2 | |
| | 0.3 | |
| | 0.4 | |
| Fully Turbulent Flow | 0.5 | Orifice Flow, Tortuous Path |
| | 0.6 | |
| Mostly Turbulent Flow | 0.7 | Long or Spiral Path |
| | 0.8 | |
| Mostly Laminar Flow | 0.9 | Microtube |
| Fully Laminar Flow | 1.0 | Capillary Flow |

As mentioned previously, laminar flow emitters are susceptible to variations in water temperature. To maintain an application uniformity of 90% throughout the trickle system, this temperature effect must be known. Water temperatures tend to increase along the lateral line, as duration of exposure to the sun increases. The flow exponent x can be used to determine the temperature effects on laminar flow emitters.

The value of x for a given emitter can be determined experimentally by operating the emitter at two pressures, $H_1$ and $H_2$, and measuring the respective flow rates $Q_1$ and $Q_2$. The operating pressures selected should be near the upper and lower limits of the emitter's normal operating range (10 and 25 psi). A long enough time duration, possibly 30 minutes, is required to obtain an accurate measure of water volume.

$$x = \frac{\log (Q1-Q2)}{\log (H_1/H_2)}$$

Table 4.4 can be used to determine the temperature effects on partially or fully laminar flow emitters once the flow exponent x is known.

Table 4.4 Temperature Correction Factors for Laminar Emitter Flow Rates

| Temperature | | Correction Factor | | |
|---|---|---|---|---|
| °C | °F | x = 0.6 | x = 0.8 | x = 1.0 |
| 5 | 41 | 0.94 | 0.87 | 0.63 |
| 10 | 50 | 0.95 | 0.92 | 0.75 |
| 15 | 59 | 0.98 | 0.95 | 0.87 |
| 20 | 68 | 1.00 | 1.00 | 1.00 |
| 25 | 77 | 1.02 | 1.05 | 1.13 |
| 30 | 86 | 1.04 | 1.10 | 1.28 |
| 35 | 95 | 1.06 | 1.14 | 1.43 |
| 40 | 104 | 1.08 | 1.19 | 1.56 |
| 45 | 113 | 1.10 | 1.24 | 1.70 |
| 50 | 122 | 1.12 | 1.29 | 1.85 |

The application uniformity of a trickle system should only be effected by temperature for laminar flow emitters on a hot day, when incoming cool irrigation water is slowly heated as it travels along the lateral. The severity of this process should be evaluated to determine if any corrective measures should be taken.

## Pressure Effects on Trickle System Uniformities

Trickle irrigation emitter emission uniformities can be expressed by the following equation:

$$EU = (1 - 1.27\,Cv/\sqrt{n})\,(Qm/Qa)$$

where EU = emission uniformity as a decimal
n = number of emitters per plant for point source emitters
= for line source emitters, the plant spacing divided by the orifice spacing or 1, whichever is greater.
Cv = manufacturer's coefficient of variation for the emitter type. See Table 6.5
Qm = minimum emitter flow rate (gph) for the minimum pressure Hm
Qa = the average emitter flow rate (gph) for the average pressure Ha.

The first factor in the formula expresses emitter flow rate variance due to the manufacturer's variation Cv. This factor is reduced significantly by increasing the value of n. Installing two or more emitters per plant therefore reduces the impact of this variation on system uniformity. The second factor (Qm/Qa) expresses emitter flow rate variation resulting from pressure differences. Table 4.5 provides flow exponent x and manufacturers variation coefficient for various emitter types. Table 4.6 illustrates the relationship between efficiency of application and pressure variation for emitter flow exponent values of 1.0 and 0.5.

As expected, the efficiency of application for a laminar flow emitter (x = 1.0) is much lower than turbulent flow emitters (x = 0.5) for severe pressure variations.

The efficiency of application (EA) for a trickle system is expressed as:

$$EA = \frac{\text{Water in Root zone}}{\text{Total Water Applied}} \times 100$$

Graphical analysis shows that the efficiency of application can also be described as:

$$EA = \frac{Qm}{Qa}$$

The efficiency of application can be related to pressure variation by using the equations:

$$Qm = Kd\,(Hm)^{x} \text{ and } Qa = Kd\,(Ha)^{x}$$

By dividing:

$$EA = \frac{Qm}{Qa} = \left(\frac{Hm}{Ha}\right)^{x}$$

The efficiency of application is therefore a function of pressure variation (Hm/Ha) and the emitter flow exponent x.

Table 4.5 Emitter Performance Data

| Emitter Type | *Figure 4.1 | Flow Exponent (x) | Manufacturer's Variation Coefficient (Cv) |
|---|---|---|---|
| **Orifice Type** | | | |
| Vortex | B | 0.42 | 0.07 |
| Turbo Key | | 0.50 | |
| $E_2$ | | 0.70 | |
| Multiple Flexible | CD | 0.70 | 0.05 |
| Ball & Slotted | E | 0.15 - 0.50+ | 0.25 |
| **Long Path Types** | | | |
| Microtube | F | 0.70 | 0.05 |
| Spiral long path | G | 0.75 | 0.06 |
| Compensating long path | H | 0.20 - 0.40 | 0.06 |
| Tortuous long path | I | 0.65 | 0.02 |
| **Short Path Types** | | | |
| Groove and Flap | J | 0.33 | 0.02 |
| Slot and Disc | K | 0.11 | 0.10 |
| **Line Source** | | | |
| Porous Pipe | | 1.0 | 0.40 |
| Biwall | L | 0.47 - 0.61 | 0.10 - 0.17 |

From Rain Bird - Ken Solomon.

* Letters refer to sketch in Figure 4.1 Page 4-2.
+ Range refers to different emitters of the same general type.

Table 4.6 Efficiency of Application versus Pressure Variation

| Pressure Variation Hm/Ha | Effiency of Application (Qm/Qa) | |
|---|---|---|
| | x = 0.5 | x = 1.0 |
| 95% | 97% | 95% |
| 90% | 95% | 90% |
| 85% | 92% | 85% |
| 80% | 89% | 80% |
| 75% | 87% | 75% |
| 70% | 84% | 70% |
| 60% | 77% | 60% |
| 50% | 71% | 50% |

To design an efficient trickle irrigation system, the designer must be able to determine the maximum allowable pressure variation. The emission uniformity can be rewritten as:

$$EU = (1 - 1.27\ Cv/\sqrt{n})\ (Hm/Ha)^{x}$$

This can be rewritten for pressure variation as:

$$\left(\frac{Hm}{Ha}\right) = \left(\frac{EU}{1 - 1.27\ Cv/\sqrt{n}}\right)^{1/x}$$

Table 4.7 shows calculated values of EU for varying parameters using the formulas shown above.

Table 4.7 Trickle Irrigation Emission Uniformities

| EU | Pressure Variance (Hm/Ha) | Emitters per Plant (n) | Emitter Flow Exponent (x) | Manufacturer's Variance Coefficient (Cv) |
|---|---|---|---|---|
| .91 | .95 | 2 | 0.50 | 0.07 |
| .90 | .95 | 2 | 0.70 | 0.07 |
| .80 | .95 | 2 | 0.50 | 0.20 |
| .79 | .95 | 2 | 0.70 | 0.20 |
| .87 | .90 | 2 | 0.70 | 0.07 |
| .84 | .90 | 2 | 0.70 | 0.10 |
| .76 | .90 | 2 | 0.70 | 0.20 |
| .84 | .85 | 2 | 0.70 | 0.07 |
| .86 | .85 | 2 | 0.50 | 0.07 |
| .84 | .85 | 2 | 0.50 | 0.10 |
| .80 | .80 | 2 | 0.70 | 0.07 |
| .84 | .80 | 2 | 0.50 | 0.07 |
| .90 | .80 | 2 | 0.20 | 0.07 |

The pressure variance (Hm/Ha) is described as the minimum pressure (Hm) divided by the average pressure (Ha). The actual operating pressure range Hmax to Hmin will be larger than the pressure variance term used in the EU formula. A good estimate of the maximum operating pressure range is to double the difference calculated by the pressure variance term.

The following design criteria can be obtained from the data generated in Tables 4.5, 4.6 and 4.7.

i) To obtain a minimum efficiency of application of 95% a fully turbulent flow emitter must be operated within a maximum pressure range of 20% of the emitter operating pressure. A laminar flow emitter must be operated within a maximum pressure range of 10% of the emitter operating pressure.

ii) The recommended emission uniformity for a trickle irrigation system is 90%. The minimum emission uniformity for point source emitter systems is 85%. In order to achieve an EU of 85%, a point source emitter must be operated within a maximum pressure range of 20% of the emitter operating pressure.

iii) A manufacturer's variance coefficient of 0.10 is acceptable for the EU and maximum pressure range of point source emitters listed in (ii). If variance coefficients exceed 0.10 the maximum pressure range should be decreased accordingly.

iv) The minimum emission uniformity for line source systems is 80%. A lower EU value is selected for line source systems since the manufacturer's variance coefficient are 0.20 or higher for these systems. To achieve an EU value of 80%, the maximum pressure range for line source systems is 10 - 15% of the system operating design pressure.

Example

What is the recommended operating pressure range of a trickle system with an average operating pressure of 15 psi and an allowable pressure variance of 0.95?

Ha = 15 psi
Hm/Ha = 0.95
Hm = 0.95 x 15 psi = 14.25 psi

Difference between Ha and Hm = 15 - 14.25 = 0.75.

Hmax is therefore 15 psi + 0.75 psi = 15.75 psi.

The operating pressure range for this system is 14.25 to 15.75 psi.

# V EMITTER PLACEMENT

An important factor in the design of a trickle irrigation system is the selection and placement of emitters. Trickle irrigation systems are installed in a variety of ways; buried underground, laid on top of the ground laid underneath plastic mulches and strung above the ground suspended on plant support systems. The mode of installation selected will depend on farm management, crop growth, and the type of emitter used.

## 5.1 DETERMINING THE NUMBER OF EMITTERS PER PLANT

The selection of how many emitters per plant should be used will depend upon:

- **Wetting pattern of the soil from the emitter used.** The wetting pattern that develops depends on the emitter discharge rate, emitter spacing and soil type. The diameter of the wetted soil volume will generally increase with an increase in the soil clay content or an increase in emitter discharge rate. Table 4.1 provides information on lateral spread of water from point source emitters. Figure 4.2 in the previous chapter shows the ideal situation where the wetted volume from one emitter will reach the other to form a continuous wetted band along the crop row. Note how a soil boundary layer may effect the soil wetted volume. In clay soils the soil wetted volume depends mainly on soil capillary forces while gravitational forces have a greater effect in sandier soils. The wetted volumes in sandy soils are less, therefore requiring closer emitter spacings requiring closer emitter spacings.

  A trickle irrigation system should wet at least 40% of the plant's root volume that would be developed under a conventional sprinkler irrigation system.

- **Maximum duration of application.** The duration of application should not exceed 12 hours at one time. Once the peak crop water use rate has been calculated and the irrigation interval determined the trickle system must be able to apply this amount of moisture within the 12 hour interval. The number of emitters per plant may have to be increased to accomodate the maximum 12 hour application duration or the emitter flow rates must be increased.

- **Type of crop and plant spacing.** The type of crop and plant spacing will assist in determing the type of emitter, emitter discharge rate and emitter location. (See Table 5.1 and Section 5.2).

Table 5.1 provides a guide in determining the number of emitters that are required per plant.

Selecting emitter placement for tree fruits presents additional problems. A mimimum of 40% of the tree root volume should be watered in a symmetrical fashion to ensure that a sturdy tree is developed. Poor tree stability will only be detected in eight or more years after planting if the water is inadequately distributed. In valleys that have a prevailing wind direction it is particularly important that the trees are properly anchored.

| Table 5.1 | Emitters Per Plant |
|---|---|
| **Crop Type** | **Emitter Recommendations** |
| Vegetables (single row) | Linear tape (line source) system.<br>Orifice spacing not to exceed 1 1/2 times the plant spacing along the row. |
| Vegetables (double row) | Linear tape system.<br>Orifice spacing not to exceed the plant spacing along the double row. |
| Grapes | 1 - 2 gph point source emitters. Emitter spacing to match plant spacing but emitters can be spaced closer in sandy soils. |
| Strawberries | Linear Tape System.<br>Orifice spacing should not exceed 24 inches. A 12" spacing is recommended. |
| Raspberries | 1 - 2 gph point source emitters. Use approximately one emitter for every 2 plants. Emitter spacing may range from 4 to 6 ft apart depending on soil type. |
| Blueberries | 1 - 2 gph point source emitters. Emitter spacing to match plant spacing. |
| Tree Fruits (Double Row planting) | Tree spacing per row is 6 ft or less.<br>(i) Space point source emitters half way between trees. Each row will require a lateral line. (See figure 5.9). |
| Tree Fruits (Dwarf Trees) | Tree Spacing is approximately 8 ft apart.<br>(i) Use two 1 gph point source emitters per plant. Emitters to be spaced 2 to 3 ft from the tree trunk.<br>(ii) Use 1 microjet per tree. Microjet to be spaced halfway between trees (360° head) or at the base of each tree using a 270° or 180° head. |
| Tree Fruits (Semi Drawf) | Tree spacing greater than 8 ft apart.<br>(i) Use a minimum of two 1gph emitters per plant. For tree spacings exceeding 15 ft, 3 or more emitters may be required. Emitters to be 2 1/2 - 3 ft from tree trunk.<br>(ii) Use 2 microjets per tree. Microjets to be installed at tree with two 180° heads discharging away from tree trunk. |

## 5.2 EMITTER LOCATION AND INSTALLATION

### Vegetables

Eggplants, peppers, tomatoes, cantaloupes, squash and strawberry crops all do well with a properly installed trickle irrigation system. These row crops are grown in single rows, double rows with and without mulches. Linear tape trickle irrigation systems are normally used with these types of crops. These line source lateral lines can be placed adjacent to the crop rows, below the ground surface or beneath the plastic mulches. If buried the orifices should be pointed down to reduce potential plugging from sediment settling onto the orifices on shutdown. The following figures illustrate installation of line source emitters on row crops.

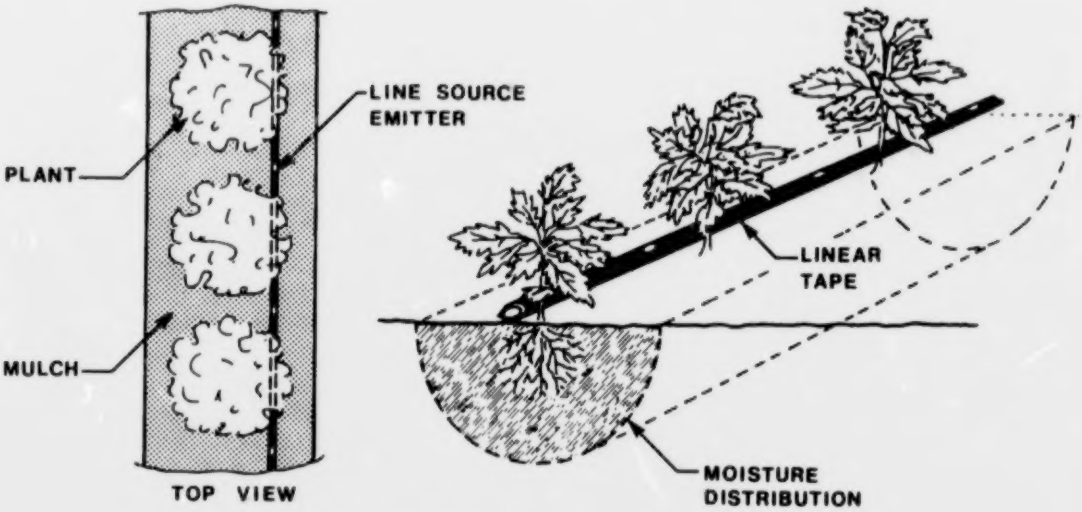


Figure 5.1 Linear Tape Installation for Single Row Cropping.

It is best to keep the linear tape system as close to the crop row as possible. For seed germination the lateral should be no further away than 6" and should not be further away than 12" for transplants.

If double row cropping is used the lateral can be placed between the two rows as shown in Figure 5.2 Placing of the laterals may be important in situtions where mechanical tilling, hoeing, pruning or other operations are done while the lateral is in place.

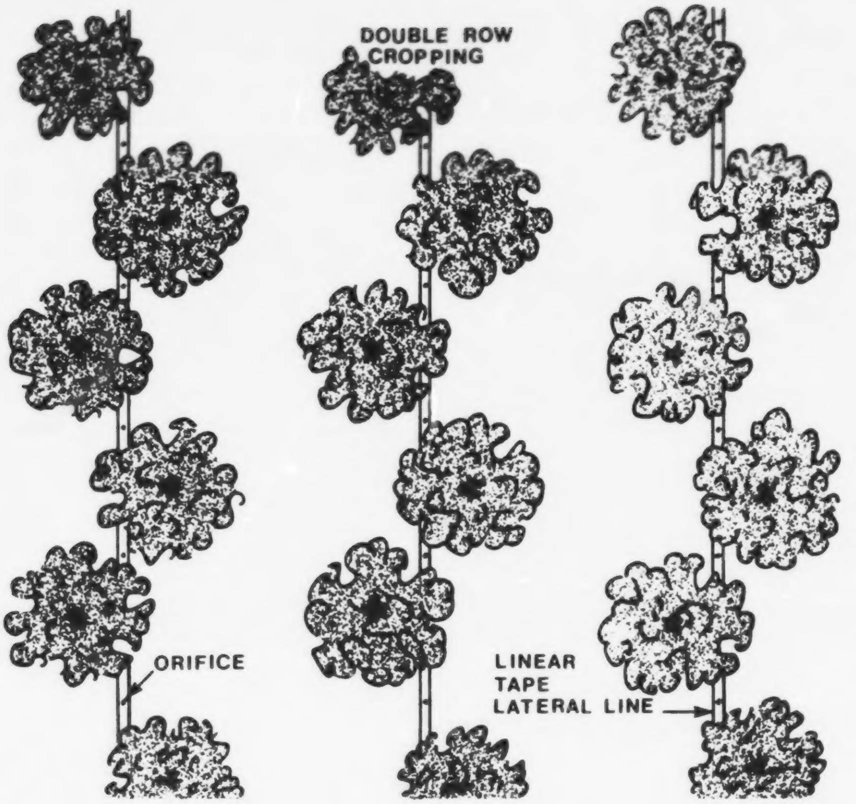


Figure 5.2 Linear Tape Installation for Double Row Cropping

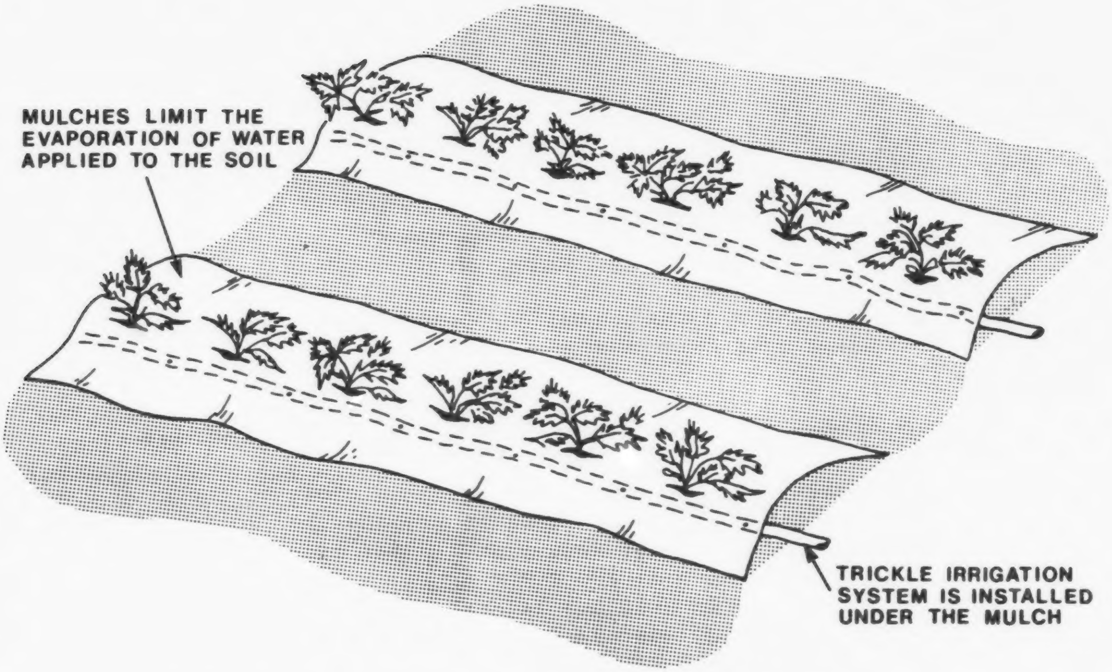

MULCHES LIMIT THE EVAPORATION OF WATER APPLIED TO THE SOIL
TRICKLE IRRIGATION SYSTEM IS INSTALLED UNDER THE MULCH

Figure 5.3 Linear Tape Installation Using Plastic Mulches

Water use efficiency is increased when plastic mulches are used to reduce evaporation from the soil surface. Mulches also may increase the surface wetted area of soil under the mulch. Black polyethylene mulches are most commonly used for tomatoes, peppers, strawberries, eggplants, etc. The lateral line is laid out first with the mulch placed overtop at a later date. Holes are then punched into the mulch to plant the crop. Care should be taken to ensure the lateral line will not be in the way of the planting process.

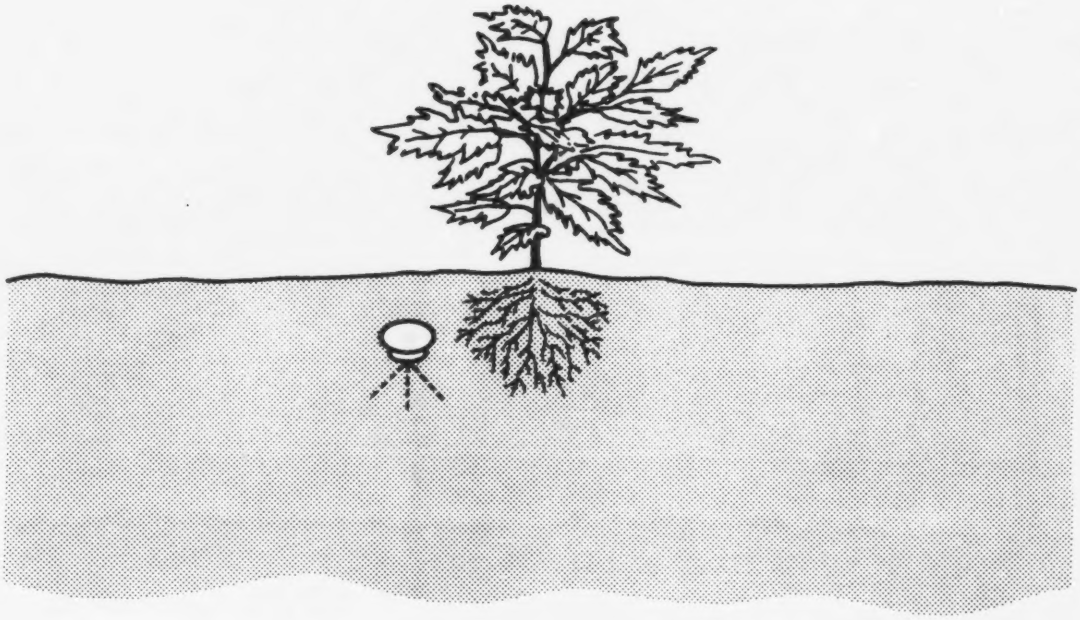


Figure 5.4 Buried Linear Tape Systems

Burying trickle lateral lines will reduce evapotranspiration rates, may reduce rodent damage and protect the lateral from surface field operations but will create other problems. Checking the system for possible maintenance requirements is the biggest concern. Buried systems should be placed with the orifice pointing down to prevent water from the outlets coming to the surface as well as reducing the amount of sediment that may settle on the orifice when the system is shut down.

## Berries and Vines

Point source emitter systems for these types of crops are usually placed on the surface or suspended on the tressles. Emitters are spaced so that the wetted pattern from each emitter join to form a continuously wetted band along the crop row. If emitters are to be installed manually, the emitter should be installed on the bottom of the lateral. This will allow the emitter to drip at the location desired. Figures 5.5 and 5.6 indicate the lateral line layouts and moisture distrubution.

Lateral lines suspended on tressels always have some sag along the line. Water discharged from in-line emitters will tend to flow along the lateral and drip at the sag points. It is therefore important to support the lateral to reduce the sag.

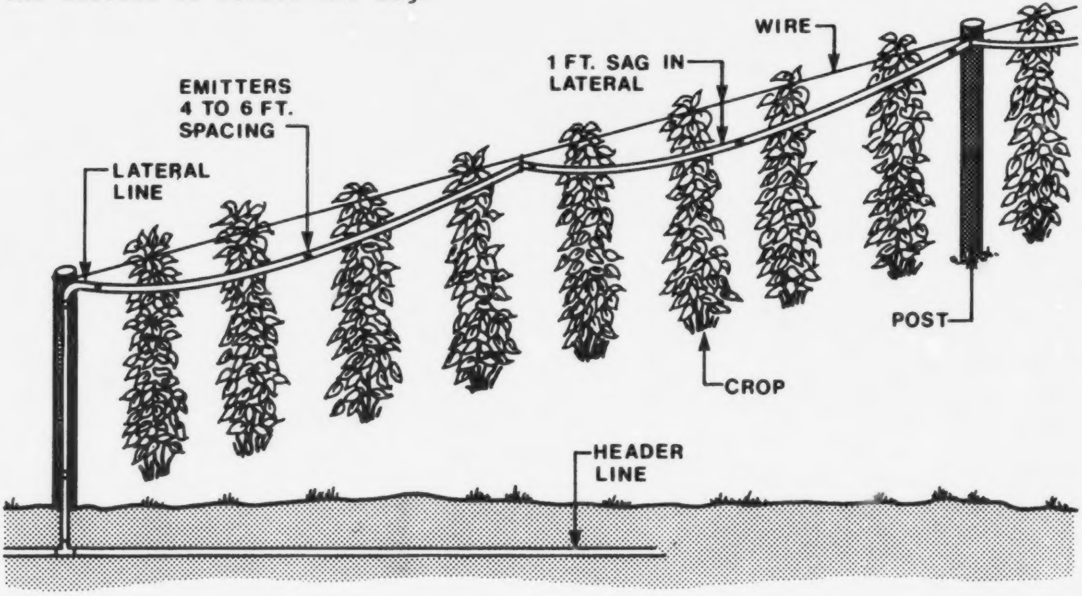


Figure 5.5 Lateral Line Layout For Berry and Vineyard Crops

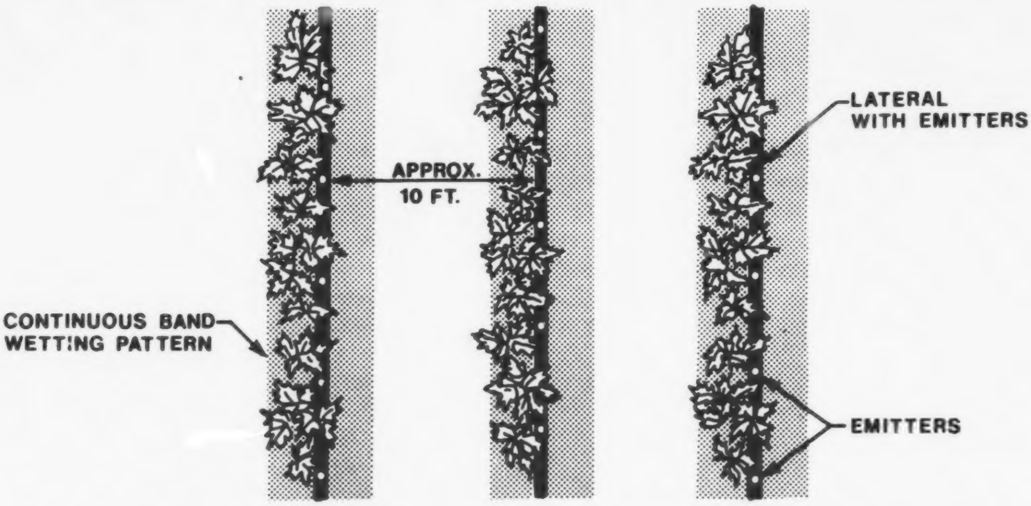


Figure 5.6 Moisture Distrubution from Lateral Line

## Tree Fruits

Tree fruits can use both point source and spray emitter systems. The type of emitter system selected may depend upon water supply, water quality, plant spacing, soil type and farm management. Figures 5.7 and 5.8 indicate common emitter installation for point source systems on tree fruits. Figure 5.9 indicates a point source emitter system for double row high density tree fruit plantings.

Point Source

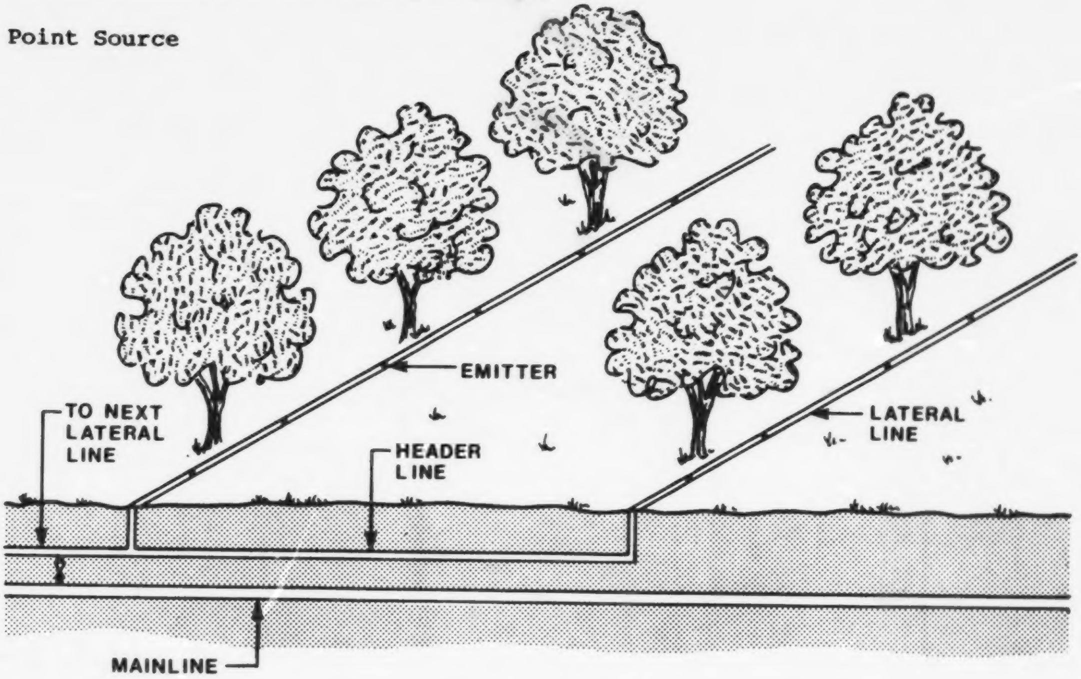


Figure 5.7 Point Source System Layout for Tree Fruits

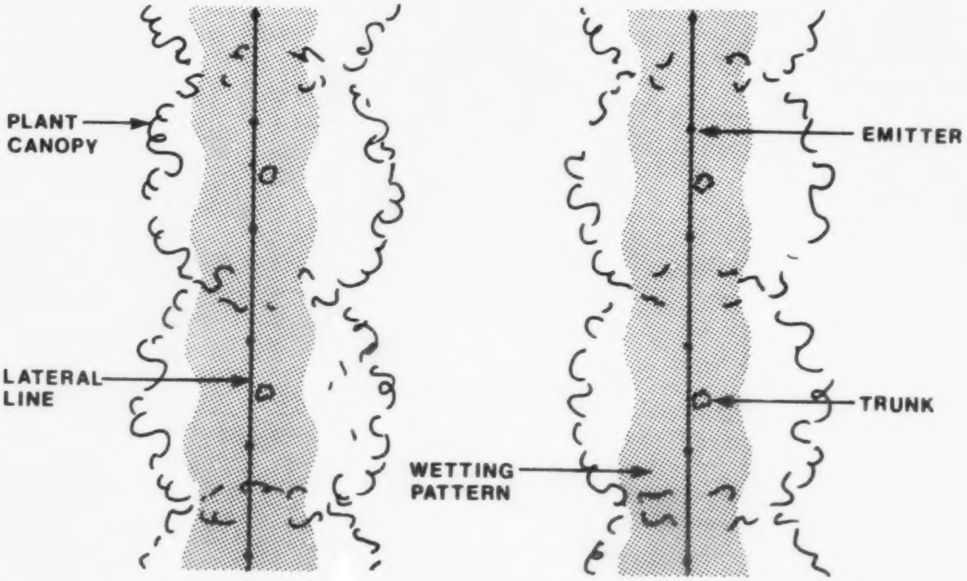


Figure 5.8 Moisture Pattern from Point Source System

Emitters should be placed at the outer edge of the plant canopy for young trees and approximately one third to half the distance to the outer edge of the plant canopy for mature trees. To reduce the threat of crown rot damage the emitter should be spaced 2 1/2 to 3 feet away from the trunk for mature trees.

For high density double row cropping emitters should be placed adjacent to the trees for very young trees. As the trees mature the lateral line can be shifted so that the emitters are spaced half way between the trees. Note that each mature tree will receive moisture from three emitters if the tree spacing in the double row planting is staggered.

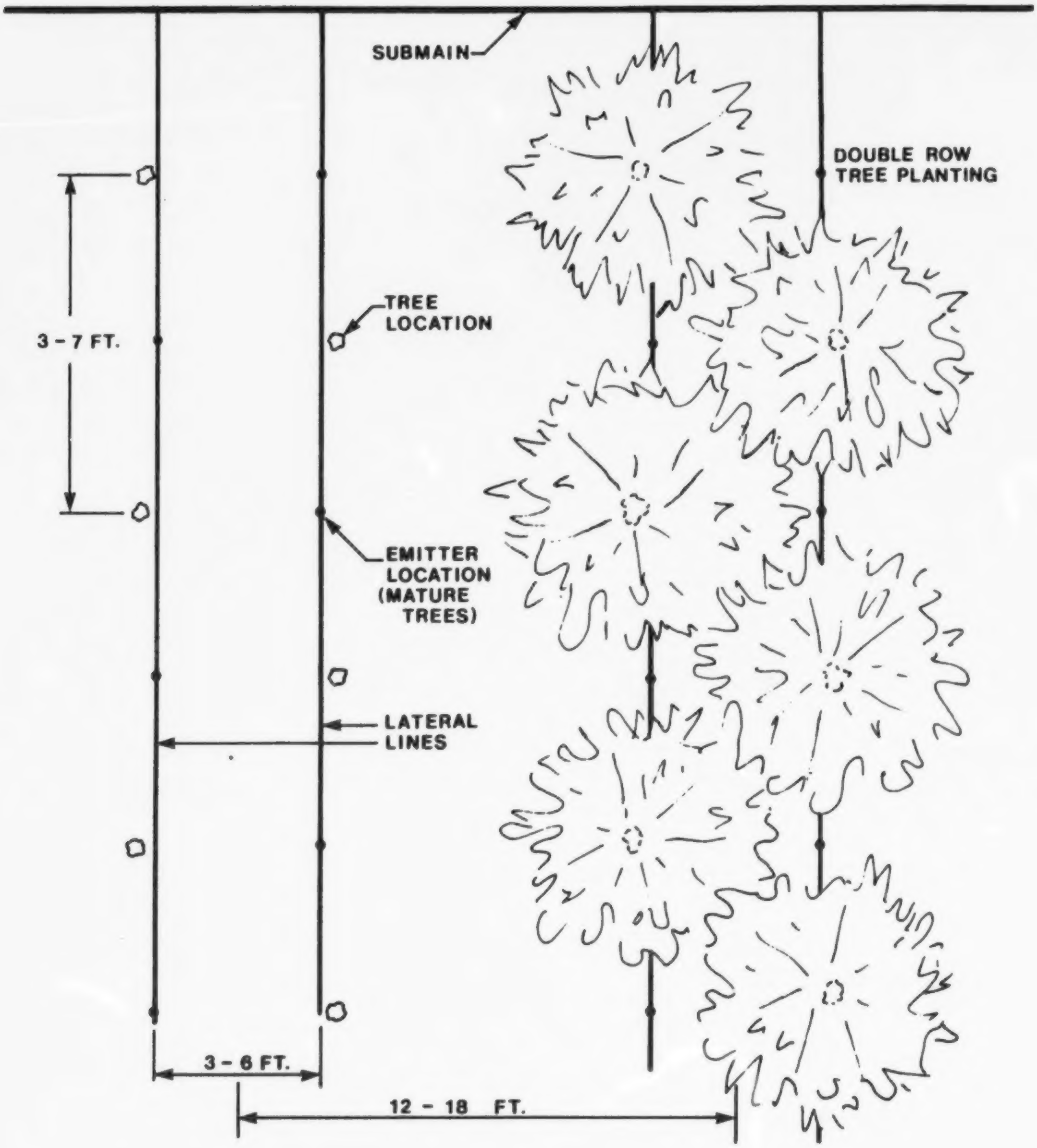


Figure 5.9 Point Source System Layout for High Density Tree Fruit Plantings

### Microjet

Since microjet systems utilize a spray pattern, the microjet head should be fixed to obtain maximum diameter of throw. Stapling the microjet to a stake obtains best results. Do not staple microjets to the tree trunk, as the staples will eventually cut through the transfer tubing with trunk growth. Figure 5.10 illustrates proper microjet installation. The lateral line can be installed either above or below ground.

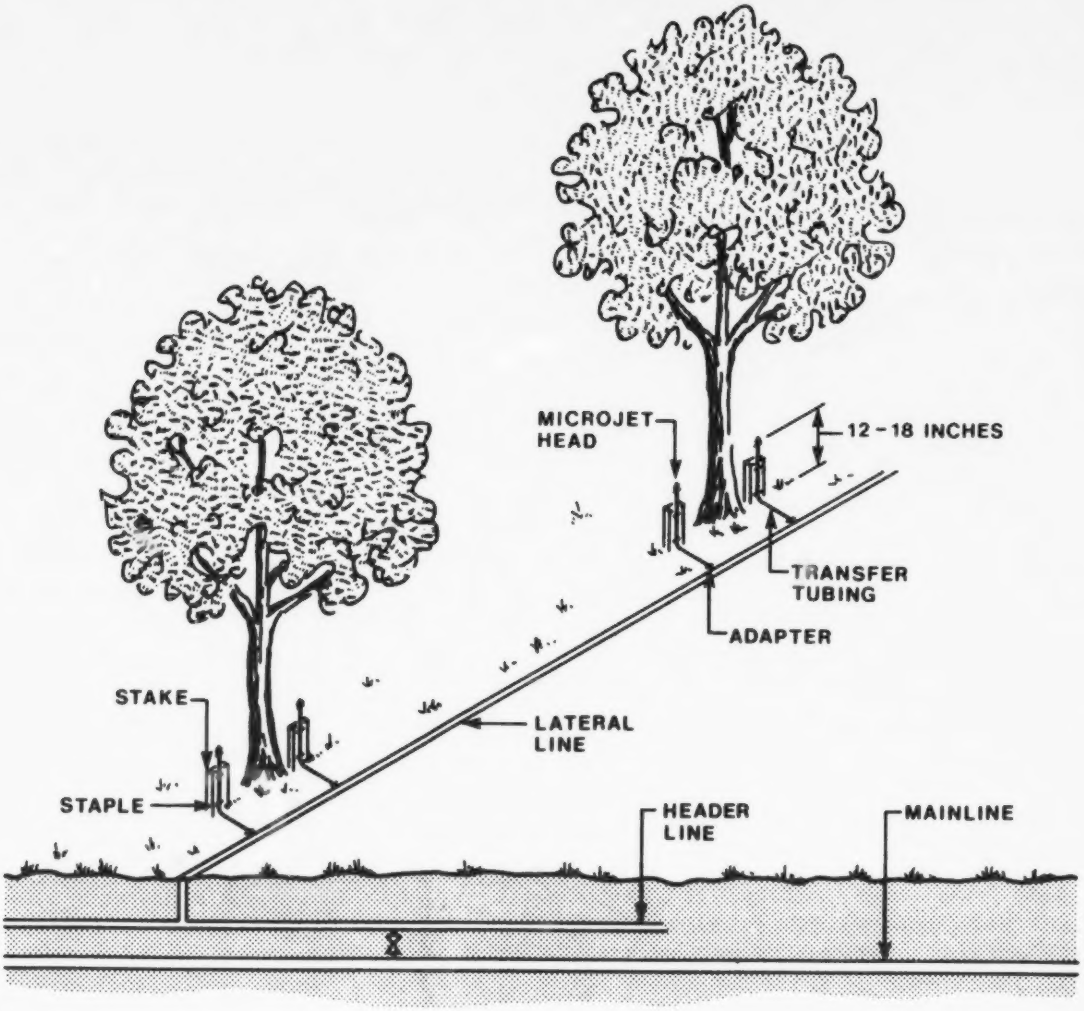


Figure 5.10 Microjet Installation

## Greenhouse Installation

Greenhouse crops are often grown in pots, bags of sawdust or other types of containers. For these types of growth mediums a trickle system is often used to supply irrigation water and nutrients. There are two types of trickle feeding systems used in greenhouses, microtube systems and emitter systems.

### Microtube

Microtubes utilize a long flow path to regulate discharge rates. Up to 6 feet of tubing may be required to obtain the desired discharge, depending on the size of tubing used. These types of installations can become awkward due to the amount of "spaghetti" tubing required.

### Emitter Systems

This type of system utilizes an emitter to regulate the flow and then uses just enough microtubing to reach from the lateral to the plant growing medium. The flow regulation is more accurate and the system is easier to monitor as the amount of microtubing is greatly reduced. See Figure 5.11.

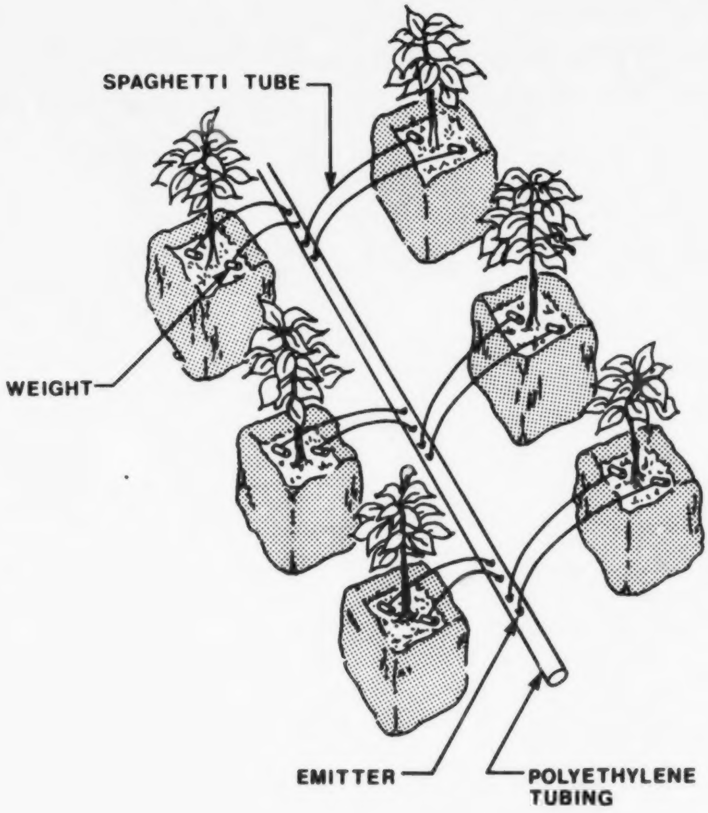


Figure 5.11 Emitter System Installation for Greenhouse or Nursery Installation

# VI SYSTEM WATER SUPPLY

## 6.1 MAINLINE SELECTION

Selection of an adequate mainline to deliver water from the source to the trickle irrigation system will depend upon:

- the amount of water to be delivered
- the allowable friction loss in the mainline
- the type of pipe to be used
- the length of mainline required

The length of mainline and amount of water to be delivered can be determined from the trickle irrigation design plan and layout. A choice of pipe material and pipe size must be made to design an irrigation mainline.

### Pipe Type Selection

There are four common types of pipe material used in irrigation systems.

**Aluminum**

Aluminum is lightweight, easy to assemble and used extensively for above ground portable irrigation systems. Aluminum pipe should not be buried unless it has a protective coating. Aluminum pipe is not often used for trickle irrigation systems.

**Steel**

Steel is more commonly used for larger diameter or high pressure installations (10" diameter and larger) where its weight and cost are not prohibitive. Steel is quite susceptible to corrosion but protection such as wrapping, galvanizing and rust resistant paints are available to allow for burial of steel pipe. Steel pipe is not commonly used for trickle irrigation systems.

**PolyVinyl Chloride (PVC)**

PVC pipe is available in numerous classes depending on the working pressures and site conditions that will be encountered. It is lightweight, durable, easy to install and has excellent resistance to most chemicals making it popular for buried irrigation systems. While ultraviolet resistant PVC is available, ordinary PVC deteriorates when exposed to sunlight and becomes brittle at freezing temperature making it impractical for most exposed work. See Table C.2 to C.7, Appendix C for friction loss values (PE) of PVC pipe.

**Polyethylene (PE)**

Polyethylene has similar characteristics to PVC except that it is more flexible. PE is more commonly used for small diameter and low pressure situations. For mainline sizes exceeding 2" or 75 psi, PVC pipe is more commonly used than PE. PE is quite responsive to temperature changes which may require special attention during installation. See Table C.1, appendix C for friction loss values of polyethylene pipe.

PVC and PE are commonly used mainline materials for trickle irrigation systems.

## Calculating Mainline Size

The mainline pipe size will be determined from the allowable friction loss and quantity of water to be delivered. The maximum flow velocity in the mainline piping should not exceed 5 ft/sec to reduce potential surge pressures. The tables in Appendix C have dark lines indicating at which flow rate the 5 ft/sec flow velocity for each pipe size is reached. Friction values below the dark lines in these tables are in excess of 5 ft/sec and should therefore be avoided.

Pipe size determination is also dependent upon the maximum allowable pressure loss in the mainline.

### Example

A trickle irrigation system requires a flow rate of 100 gpm. The water source is a gravity feed system with an elevation drop of 100 ft from the intake to the trickle system. The distance is 2000 ft. The trickle system requires 30 psi to operate. What size mainline is required?

The allowable pressure loss in the mainline is:

$$100\text{ ft} \times \frac{2\text{ psi}}{2.31\text{ ft}} = 43.3\text{ psi}$$

$$43.3\text{ psi} - 30\text{ psi} = 13.3\text{ psi}$$

$$\text{Maximum allowable friction loss per 100 ft} = \frac{13.3\text{ psi}}{2000\text{ ft}} = \frac{0.66\text{ psi}}{100\text{ ft}}$$

If class 125 PVC is used, from Table C.4, 3" Class 125 PVC has a friction loss of 0.66 psi/100 ft. Since the friction loss value is above the dark line the flow velocity does not exceed 5 ft/ sec. The mainline selected should therefore be 3" class 125 PVC pipe.

The mainline selected should be large enough to accomodate future flow requirements, be able to withstand the maximum pressures exerted on the system and be adaptable to the type of installation. Large pipe is usually a good investment but pipe cost must also be considered.

## 6.2 PUMP SELECTION

### Pump Horsepower Requirements

There are two main steps required in the selection of an irrigation system pump:

**(1) System Flow Rate Calculation**

The irrigation system flow rate is determined by calculating the flow rate of each zone and adding together the flow rates of each zone that are operating at the same time.

**(2) Total Dynamic Head Calculation**

The total dynamic head ($H_T$) of an irrigation pump consists of four factors:

$$H_T = H_s + H_e + H_f + H_p$$

where $H_s$ = static suction head (vertical distance from the water level to the center of the pump impellor)

$H_e$ = static discharge head (elevation difference from the center of the impellor to the highest point of the irrigation system)

$H_f$ = friction head (total friction loss of all suction and mainline fittings between the pump and the zone pressure control valve)

$H_p$ = pressure head (the pressure required at the zone pressure control valve)

### Calculating Pump Horsepower

The brake horsepower required by an irrigation pump can be calculated by the formula:

$$H.P. = \frac{Q \times H_T}{3960 \cdot \times E}$$

where $Q$ = trickle irrigation system flow rate (gpm)
$H_T$ = total dynamic head (ft)
$E$ = pump efficiency at the flow rate and total dynamic head required given in a decimal term.

### Example

Flow required = 100 gpm
Total dynamic head $H_T$ = 111 ft
Pump efficiency = 70% or 0.70

$$H.P. = \frac{100 \text{ gpm} \times 111 \text{ ft}}{3960 \times 0.70} = 4.0 \text{ h.p.}$$

## Centrifugal Pump

A horizontal centrifugal pump is most commonly used for irrigation applications where static suction head conditions are less than 20 ft. The pump selected should provide the operating requirements of the irrigation system at or close to its best efficiency point. (B.E.P.) The B.E.P. of centrifugal pumps vary from 45% to 80% but consideration should be given to selecting pumps that have efficiencies of 65% or better. A centrifugal pump should not be operated at less than 80% of its B.E.P. (i.e. If a pump has a B.E.P. of 80%, it should not be allowed to operate at an efficiency less than 64%).

Pump capacity and efficiency are reduced by excessively high suction lifts. To ensure efficient pump operation the calculated Total Dynamic Suction Lift (TDSL) must be less than the allowable TDSL shown on the pump performance curves.

Centrifugal pumps are normally used for trickle irrigation systems pumping from lakes, rivers, creeks or shallow wells.

## Turbine and Submersible Pumps

Turbine and submersible pumps are used for well and high lift installation. Wells exceeding 25-30 ft in depth will require a turbine or submersible pump. Turbines are generally used for total pressure requirements exceeding 500 ft.

For optimum life turbines should not exceed 1800 rpm. Submersible pumps usually operate at 3600 rpm which may allow for smaller well diameters than a turbine pump. Wells should be constructed at least one nominal size larger than the pump size. Table 9.1 can be used to select a well diameter size.

Table 6.1 Recommended Well Diameters

| Anticipated Well Yield (gpm) | Nominal Size of Pump Bowls (in) | Optimum Size of Well Casing (in) | Smallest Size of Well casing (in) |
|---|---|---|---|
| Less than 100 | 4 | 6 ID | 6 ID |
| 75 to 175 | 5 | 8 ID | 8 ID |
| 150 to 400 | 6 | 10 ID | 8 ID |
| 350 to 650 | 8 | 12 ID | 10 ID |
| 600 to 900 | 10 | 14 OD | 12 ID |
| 850 to 1300 | 12 | 16 OD | 14 OD |
| 1200 to 1800 | 14 | 20 OD | 16 OD |
| 1600 to 3000 | 16 | 24 OD | 20 OD |

# VII WATER TREATMENT REQUIREMENTS

An emitter utilizes small flow paths and orifices to achieve a low flow rate at a low pressure requirement. These small paths and orifices are easily susceptible to plugging by foreign material in the irrigation water supply. An emitter can become totally plugged or its flow rate reduced due to:

- organic material carried by the water supply
- silts, clays and other inorganic particulates in the water supply
- growth of algae and other bacterial slimes within the lateral lines and emitters
- precipitation of chemicals inside the trickle system

Some method of water treatment is required for successful operation of a trickle irrigation system. Emitter plugging should not go unchecked as the uneven water distribution will lead to poor system performance and may eventually cause plant stress or damage. Selecting the degree of water treatment required will be dependent on:

- the size, nature and concentration of the contaminant in the water supply.
- the filtration requirements of the emitter selected. (Variation in orifice sizes may alter the degree of filtration)
- the trickle system design capacity
- the capital expenditure of the treatment package
- pH and chemical concentration of the water supply

## 7.1 WATER QUALITY GUIDELINES FOR TRICKLE IRRIGATION SYSTEMS

As is the case with all irrigation systems, a water sample analysis should be conducted if there are any doubts whether the water quality will have any detrimental effects on the soil or crop. Although most water supplies in B.C. are considered to be of good or excellent irrigation quality as far as the crop or soil are concerned, the majority require some type of treatment to be compatible with a trickle irrigation system. Water samples should be analyzed for the following:

**Calcium and Magnesium** Severe Ca or Mg > 50 ppm and pH > 8.0

Precipitation of calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) in lateral lines and emitters will reduce the trickle system flow rate over time. Whether these precipitates will form depends upon:

- the concentration of carbonate ($CO_3$) and bicarbonate ($HCO_3$) in the water supply
- the pH level of the water supply. If the pH level exceeds 8.0, calcium and magnesium carbonates will precipitate more readily.
- the calcium or magnesium concentrations in the water supply

Although calcium and magnesium bicarbonates exist only in solution, they are readily converted into the insoluble calcium and magnesium carbonates upon evaporation. These precipitates usually form around the emitter orifices or other sections of the trickle system that are exposed to the air. The precipitation of $CaCO_3$ or $MgCO_3$ can occur when there are low concentrations of Ca and Mg present. For Ca and Mg concentrations greater than 50 ppm and a pH level of 8 or greater the conditions are conducive to precipitates forming (See Section 7.3 for further information).

**Iron** Severe (Fe > 0.5 ppm)

The precipitation of iron (Fe), either by bacterial activity or by a chemical reaction will clog emitter passages over time. Iron can become a problem at concentrations as low as 0.1 ppm. Iron bacteria oxidize soluble ferrous oxide into insoluble ferric oxide, forming a reddish filamentous slime which attaches to the trickle system components.

Chemical precipitation of iron usually occurs when water is pumped from an aquifer, with conditions that favour the solubility of iron, into the irrigation system where the change in environment favours precipitation. Pressure, temperature and pH are the most important variables determining iron solubility. Concentrations of iron around 0.5 ppm in the right conditions can be considered severe. (See section 7.3).

**Sulphur** Severe (S > 0.5 ppm)

Sulphur bacteria may produce white cottony balls of slime which can completely block emitter orifices. If a steel screen is used as a filter, interaction between Fe and S can cause iron sulphide precipitates. Sulphur bacteria can be active at sulphur (S) concentrations as low as 0.1 ppm. Concentrations of S greater than 0.5 ppm can be expected to require treatment. (See Section 7.3).

**Inorganic Solids**

Inorganic matter consists of clays, silts and minerals that are in a solid form. If a water supply consists only of inorganic solids a screen mesh filter should suffice. The mesh size will depend on the type of emitter used. (See table 7.3). The type of screen filter selected is dependent upon the degree of inorganic solid loading in the water supply. The following can be used as a guide:

| | |
|---|---|
| . < 10 mg/L (inorganic solids with particles greater than 100 microns (0.004 in) in diameter | - remove with a manual flush screen mesh filter |
| . >10 mg/L (inorganic solids with particles greater than 100 microns in diameter) | - removal with an automatic backflush screen mesh - filter may be desired. |

Particles less than 100 microns in diameter may pass through the irrigation system if iron and sulphur concentrations are not too high. Iron and sulphur bacterial slime cling to these smaller inorganic particles which can then eventually build up into larger particles. (See Screen mesh filters section for additional information.)

### Organic Solids

Organic matter consists of algae, weeds, leaves, bacterial slimes or any other material that is or was alive at one time. Water supplies that contain organic debris should utilize a sand filtration system. Screen mesh systems plug up too quickly with organic matter. Sizing the sand media filter will depend upon the degree of debris loading and the emitter characteristics (See Sand Media Filter Section). The type of sand selected is dependent upon the emitter orifice size and can be determined from Table 7.3. The following can be used as a guide to determine whether a manual or automatic backflush system should be used.

- < 10 mg/L of organic matter (particles greater than 100 microns (.004 inches) in diameter) - a manual backflush sand media filter should suffice providing the filtration unit is sized properly
- > 10 mg/L of organic matter (particles greater than 100 microns in diameter) - an automatic backflush unit may be required
- slug loadings of organic solids with particles under 100 microns - high suspended solid loadings of this type of material may not pass through the trickle system. Automatic backflush sand media filters may be required.

A sand media filtration system will remove organic and inorganic material entering the trickle irrigation system from the water supply. Organic matter such as bacterial slime that develop downstream of the filtration unit must be removed by chemical treatment and line flushing.

## 7.2 SELECTING A FILTRATION SYSTEM

The two basic types of filtration equipment used for trickle irrigation are sand media and screen mesh filters. A comparison of the sand media filtrative capacity vs. an equivalent screen mesh is given in Table 7.1. A sand media uniformity coefficient of 1.5 must be obtained before the screen mesh designation shown will be reached. (See Sand Media Section for further explanation of sand media grades).

Table 7.1 Comparison of Sand Media Filter and Screen Mesh Equivalent

| Sand Designation Number | Screen Mesh Equivalent |
|---|---|
| # 8 crushed granite | 70 |
| #11 crushed granite | 140 |
| #16 silica sand | 200 |
| #20 silica sand | 230 |

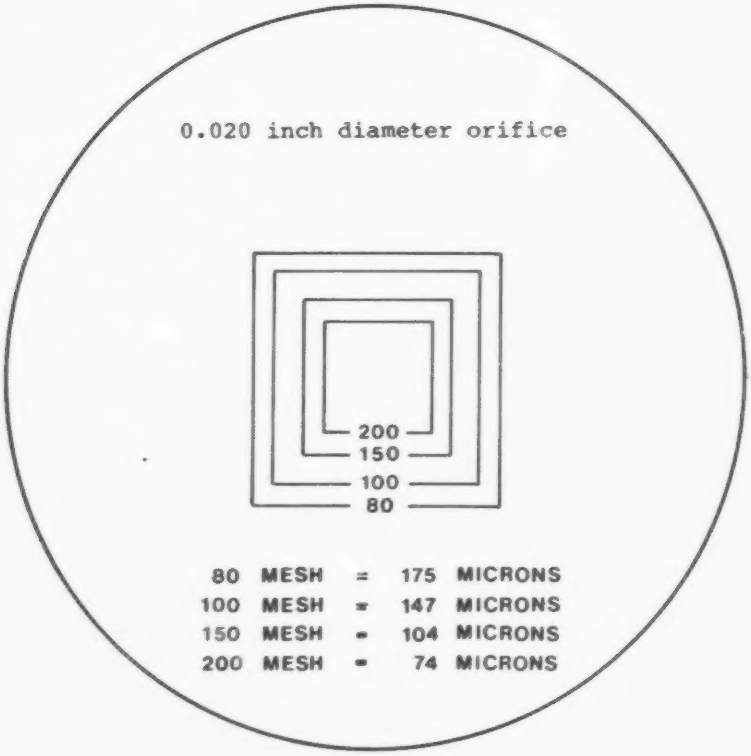


Figure 7.1 Comparison of Screen Mesh Sizes with a .020" Orifice

The size of the emitter orifice determines the quality of filtration that is required. Suspended solids are capable of plugging an emitter orifice by forming a bridge network of up to eight particles. Figure 7.1 graphically shows the various mesh sizes versus the size of a .020 inch inch diameter orifice.

To prevent the buildup of this bridge network, a filtration unit must be able to remove all particles that are larger than one-eighth of the emitter orifice diameter. In some instances particles larger than one-tenth of the emitter orifice diameter may have to be removed. Table 7.2 provides information on the filtrative capacity of various mesh sizes. Screens are classified by the opening size. The mesh number refers to the number of openings per inch.

Table 7.2 Screen Openings for Various Mesh Screens

| Screen Mesh | Screen Opening | |
|---|---|---|
| | Inches | Microns |
| 80 | 0.007 | 175 |
| 100 | 0.006 | 147 |
| 150 | 0.004 | 104 |
| 180 | 0.0035 | 88 |
| 200 | 0.003 | 74 |
| 250 | 0.0024 | 60 |

0.001 inches is equal to 25 microns.

Due to variations in wire or thread size, mesh numbers may vary slightly for the same opening size.

Table 7.3 provides information on the filtration requirement for various emitter types, using one-eighth of the emitter orifice diameter as a base requirement. The information provided in Tables 7.1 and 7.2 are used to determine the necessary screen mesh or sand media selection. The length of the flow path is also taken into account.

Table 7.3 Minimum Filtration Requirements for Various Emitter Types

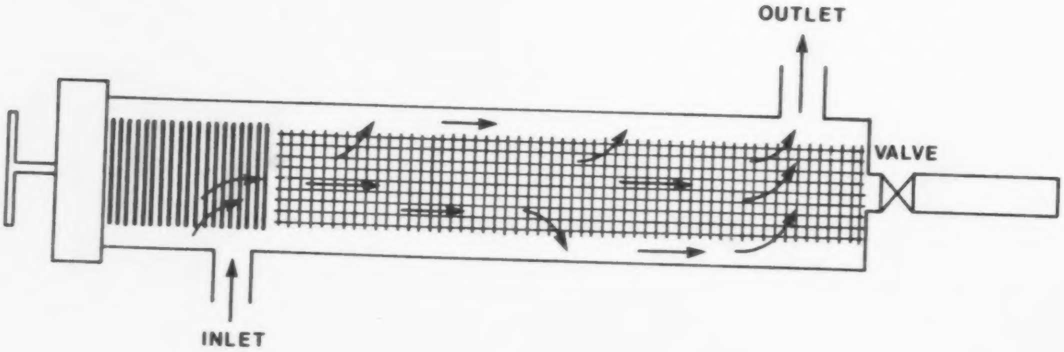
| Emitter Type | Passage Diameter | | Minimum Filtration | |
|---|---|---|---|---|
| | Inches | Microns | Screen Mesh | Sand Media |
| Microjet | .020 | 500 | 200 | #16 Silica Sand |
| | .030 | 760 | 150 | #16 Silica Sand |
| | .040 | 1120 | 80 | # 8 Crushed Granite |
| | .050 | 1270 | 80 | # 8 Crushed Granite |
| | .060 | 1525 | 80 | # 8 Crushed Granite |
| | .070 | 1780 | 80 | # 8 Crushed Granite |
| Bi-Wall | .019 | 480 | 200 | #20 Silica Sand |
| T-Tape | | | 200 | #20 Silica Sand |
| Microtube | .020 | 500 | 200 | #20 Silica Sand |
| | .025 | 635 | 150 | #16 Silica Sand |
| | .035 | 890 | 120 | #11 Crushed Granite |
| | .045 | 1140 | 80 | # 8 Crushed Granite |
| | .060 | 1525 | 80 | # 8 Crushed Granite |
| Vortex | | | 150 | #11 Crushed Granite |
| Submatic | .020 | 520 | 200 | #20 Silica Sand |
| | .030 | 760 | 150 | #16 Silica Sand |
| Dripeze | .035 | 890 | 120 | #11 Silica Sand |
| $E_2$ | .030 | 760 | 150 | #16 Silica Sand |
| Turbo Key | .035 | 900 | 120 | #11 Crushed Granite |
| Turbo Key Pressure Compensating | .025 | 650 | 150 | #16 Silica Sand |
| Netafim | .032 | 810 | 150 | #16 Silica Sand |
| All long flow Path Emitters | | | 200 | #20 Silica Sand |
| Agrifim | | | | |
| in line 1.0 gph | .056 | 1400 | 100 | #11 Crushed Granite |
| in line 2.0 gph | .063 | 1575 | 80 | # 8 Crushed Granite |
| clip on 1.0 gph | .042 | 1050 | 150 | #11 Crushed Granite |
| clip on 2.0 gph | .056 | 1400 | 100 | # 8 Crushed Granite |

A minimum 80 mesh screen should be installed on all trickle irrigation systems using emitters with orifice sizes larger than 0.06 inches (1500 microns).

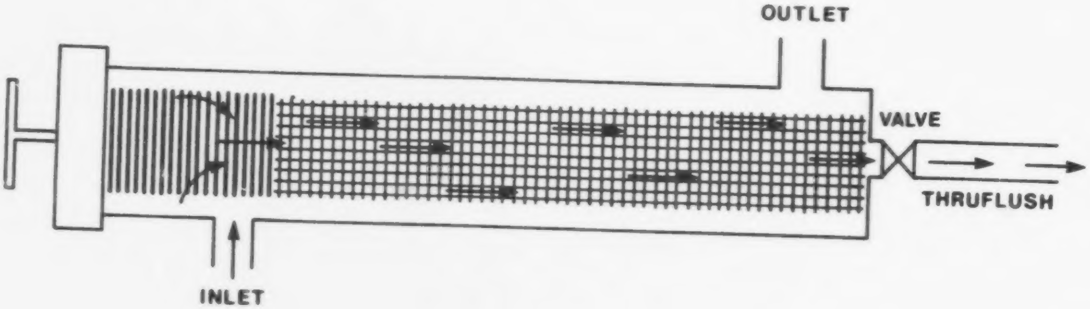
## Screen Filters

A screen filter is useful primarily for removing inorganic particles from the water supply. Water that contains a significant amount of organic contaminants cannot be successfully filtered with a screen filter. A screen filter does not have the capacity to remove and hold large amounts of organic particulate without severely curtailing the flow through the filter.

There are numerous screen filters on the market which are available for a variety of applications. The screen filter selected should be easily cleaned, rated to handle the trickle system design capacity and provide the degree of filtration required for the emitter types used. A trickle irrigation system filter that is often used is the thru-flush screen filter.



FILTRATION MODE



THRUFLUSH MODE

Figure 7.2 Thruflush Screen Filter Operation

During the filtration mode particles are filtered out of the water on the inside of the screen mesh. (See Figure 7.2). This type of screen can be quickly cleaned by opening the flush valve and allowing a gush of water to wash the accumulated contaminants out the flush port. A polymeric screen mesh, available in 30 to 200 mesh, is often used for trickle irrigation systems. When installing a screen mesh filter the outlet should be located so that debris from the screen will not drop into the outlet port upon screen removal.

Screens that are manually cleaned should use a mesh filter that flows from the outside to the inside so that repairs and cleaning can be done more easily.

A thruflush screen filter, as some other filters, can be converted to automatic operation by using a pressure sensitive flush valve. The pressure before and after the screen is monitored. When the pressure difference reaches a preset amount the valve is activated and flushes the screen.

### Sizing a Screen Mesh Filter

The accepted flow velocity through a screen mesh filter is 0.5 ft/sec. When selecting a mesh filter, it is wise to check these specifications to ascertain whether it meets this standard. All mesh filters are designed and rated to provide a maximum gpm flow rate with average water source conditions. If heavy slug loadings occur or if poor water conditions exist, additional filter surface area will be required to provide the same filtered flow rate.

The capacity of a mesh filter at a 0.5 ft/sec flow velocity through the mesh can be calculated by:

$$\textbf{Screen Open Area (ft}^2\textbf{) x 225 = filter capacity in gpm}$$

Example:

What is the rated flow of a mesh screen with a surface area of 3 $ft^2$ and an open area of 35%.

Screen open area = 3 $ft^2$ x 0.35 = 1.05 $ft^2$

Maximum rated flow = 1.05 $ft^2$ x 225 = 236 gpm

It is important to determine the open area of a screen filter. Open area decreases as the screen mesh increases. Although two screen filters may have the same surface area the rated flow will vary for different mesh sizes.

## Sand Media Filters

Sand media filters are most effective for the removal of suspended inorganic and organic particulates from the water supply. These types of filters are capable of extracting and retaining large volumes of suspended solids while continuing to deliver the rated flow of filtered water. Sand filters should be used instead of screen filters whenever the water supply contains a significant amount of organic debris.

During the filtration mode, the supply water passes from the top to the bottom of the filter bed (See Figure 7.3). The filter is designed so that water passes uniformly throughout the filter bed, preventing water channelling through the sand media.

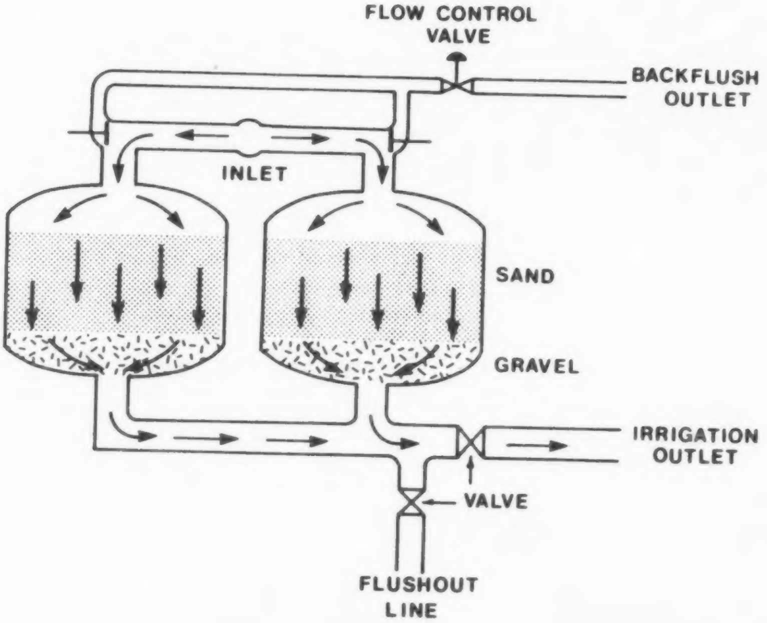


Figure 7.3 Sand Filter - Filtration Mode

Sand media filters are cleaned by reversing the water flow through the bed. This process expands the sand media allowing it to release any trapped debris out the backwash line. (See Figure 7.4). The backflush flow rate must be sufficient to expand the sand media enough to purge out all particulate while ensuring that the media itself is not expelled from the tank. The dirty backflush water should be discharged to the atmosphere and allowed to drain away. During the backflush process some particulates and fine sand may be circulated to the bottom of the sand filter. To prevent this material from migrating into the irrigation system upon start-up of the filtration mode, a flushout valve after the sand filter should be momentarily activated. A sand media filter should be backflushed whenever the pressure differential across the sand bed exceeds 5 psi above the clean operating pressure differential of the sand bed.

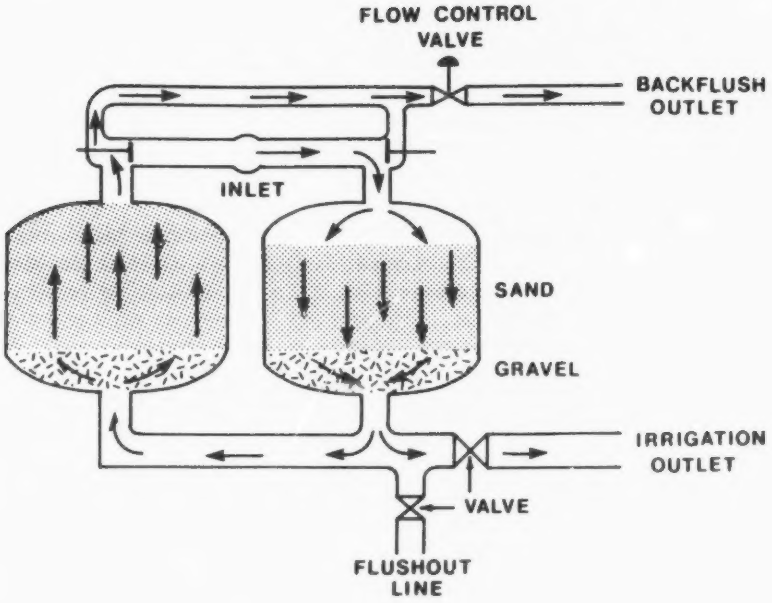


Figure 7.4 Sand Filter - Blackflush Mode

**Sizing a Sand Media Filter**

**The flow rate through a sand filter when filtering should be 20 gpm/ft$^2$ of sand bed area or less.** Sand filters must always be operated with a minimum of two units so that filtered water from one filter can be used to backflush the other. If the supply water is excessively dirty, the flow rate through the filter can be reduced to 10-15 gpm/ft$^2$ of sand bed area to increase the filtration capacity. If a flow rate of 10-15 gpm/ft$^2$ is selected more than two filtration units should be used. This is required to ensure that a sufficient flow rate is available to properly backflush the filter beds. Table 7.4 provides information on the recommended backflush flow rates for the various sand media. A flow control valve installed on the backflush line can be used to regulate the backflush flow rate and control the amount of media expelled during backflush.

Table 7.4 Minimum Backflush Flow Rates for Sand Media

| Sand Designation Number | Minimum Backflush Flow Rate |
|---|---|
| | gpm/ft$^2$ |
| # 8 | 16 |
| 11 | 15 |
| 16 | 18 |
| 20 | 15 |
| 30 | 13 |

## Example:

A farmer with a trickle system flow requirement of 200 gpm requires #16 media sand for adequate filtration of the trickle system.

A) Using a recommended filtration flow rate of 20 $gpm/ft^2$ would require 10 $ft^2$ of sand bed area. Two units of 5 $ft^2$ each would be selected. The backflush requirement per unit would be 5 $ft^2$ x 18 $gpm/ft^2$ = 90 gpm (from Table 7.4). One unit would be able to backflush the other providing the outlet to the irrigation system was shut off.

B) If a filtration flow rate of 15 $gpm/ft^2$ was selected a total of 13.3 $ft^2$ sand bed area would be required. In this case three units of 4.5 $ft^2$ each should be used. If only two units were used, one unit would be required to supply 120 gpm to adequately backflush the other. With three units, two units can combine to backflush the third unit.

Sand media filters should be operated close to the 20 $gpm/ft^2$ guideline. Lowering the filtration flow rate will increase sand bed area, possibly increasing the number of units required to provide sufficient backflushing power.

## Sand Selection

Filter sand is classified by "mean effective size" and uniformity coefficient.

- mean effective size - that size opening that will pass 10% of a representative sample of sand. An effective size of 0.80 mm means that 10% is finer than 0.80 mm.

- uniformity coefficient - a ratio of the opening size that will pass 60% of a representative sample of sand divided by the opening that will pass 10% of the same sample. A uniformity coefficient of 1.5 is required for trickle irrigation filter sand grades.

The two basic materials that should be used in trickle irrigation sand media filters are sharp, crushed silica sand or sharp, crushed granite. Selecting the sand grade required for the various emitter types can be determined from Table 7.3.

**Filter Installation**

To ensure that a trickle irrigation filter will provide the necessary filtration, maximize efficiency while minimizing cost, maintenance and labour the following points should be considered:

- The filter capacity should exceed the system flow demand.
- The filtration capability should match the requirements of the emitter types to be used.
- The filter should be located to allow access for maintenance, cleaning and disposition of backflush and rinse water.
- The filter system must be capable of expansion should this become necessary.
- The filter should be installed after the chemical and fertilizer injectors. Chemical precipitates that form during injection can then be collected by the filter system.
- A coarse screen should be installed before the trickle irrigation filter for trash removal on systems drawing from surface water sources.
- A backup screen should be installed after a sand filter to prevent sand from entering the trickle system due to sand filter malfunction or incorrect operation.
- Flow meters and pressure gauges should be installed to monitor system performance over time.

## 7.3 CHEMICAL WATER TREATMENT

Trickle irrigation systems may require chemical treatment periodically through the irrigation season to control algae, bacterial slimes due to iron and sulphur as well as chemical precipitates such as calcium carbonate and ferric oxide. Most irrigation water supplies do not require continuous treatment with chemicals. Spot treatments are suggested and should be initiated as problems begin to occur. An emitter that is totally plugged cannot usually be cleaned by chemical treatment. The chemical must come into contact with the particulates in order to have any effect.

The irrigation system manager must make a decision when or if to commence chemical treatment. The following guidelines can be used:

(i) The emitter flow rates should be monitored during the irrigation season. A reduction in emitter flow rates would indicate that chemical treatment may be necessary.

(ii) Lateral line flushing should be done at least twice during the irrigation season. If an excessive buildup of algae seems apparent, chlorine treatment may be required.

(iii) If a buildup of algae or chemical precipitates is observed a chemical treatment program should be initiated.

Most forms of algae can be controlled by chlorine or copper sulphate. Acid injection usually is required to control chemical precipitates.

### Chlorination

Chlorine is effective in controlling algae and bacterial growths as well as oxidizing iron and manganese in irrigation water supplies. In order to obtain optimum results from a chlorination program the following points are suggested:

(i) The duration of chlorine application is as important as the concentration. Test results from the Summerland Research Station indicate that treatments of 10 mg/L for 4 hours is more effective than 40 mg/L for 2 hours. When the duration of chlorine application exceeds 4 hours there appears to be no further improvement in increasing the reduced flow rates.

(ii) The maximum chlorine concentration injected should not exceed 40 mg/L. Concentrations exceeding 40 mg/L may enhance the precipitation of calcium or magnesium carbonate.

(iii) Chlorine should not be injected continuously unless specifically used to precipitate ferric oxide. Concentrations of 1 to 2 mg/L should then be sufficient. (1 mg/L of chlorine will treat 0.7 mg/L of iron).

(iv) If plugged emitters cannot be cleared with a chlorination treatment of 40 mg/L for 4 hours, manual cleaning may be necessary.

(v) Chlorine, as should all chemicals, must be injected before the filtration system. This is to ensure that any precipitates that are quickly formed will be filtered out. Irrigation water containing manganese requires extra caution, as manganese oxidizes slowly. Manganese precipitates may therefore form after the filtration system.

(vi) Lateral line flushing should always be done in conjunction with chlorination programs. The chlorine will kill living organisms but not dissolve them. Flushing is required to remove this debris from the trickle system.

(NOTE: 1 mg/L is the same concentration as 1 ppm)

The addition of chlorine to water results in the following hydrolysis reaction:

$$H_2O + Cl_2 \longrightarrow HOCl + H^+ + Cl^-$$

The hydrochlorous acid (HOCl) undergoes further reaction as:

$$HOCl \longrightarrow H^+ + OCl^-$$

Hydrochlorous acid (HOCl) and hypochlorite ($OCl^-$) are together referred to as the "free available chlorine" and coexist in an equilibrium which is effected by temperature and pH. In low pH conditions the free available chlorine is mainly in the form of HOCl. In basic or high pH conditions the free available chlorine is in the form of $OCl^-$. Hypochlorous acid (HOCl) is a much more potent algae control agent than hypochlorite (OCl). (Approximately 40 times). Therefore chlorination will be much more effective in water supplies with a lower pH value.

Chlorine is available in three forms, calcium hypochlorite, sodium hypochlorite and chlorine gas.

## Calcium Hypochlorite

Calcium hypochlorite is available in granular tablets or pellets, which are readily soluble in water and stable under the proper storage conditions. The available chlorine ($Cl_2$) will range between 60-70%. Using calcium hypochlorite as a chlorine source is not recommended for water sources already containing high calcium concentrations and pH values higher than 8.0. Acid addition will generally be required to prevent calcium carbonate precipitates from forming under these conditions.

### Sodium Hypochlorite

Sodium hypochlorite is the agent usually found in household bleach. It is available in strengths up to 18% available free chlorine. Sodium hypochlorite is readily decomposed by light and heat and must therefore be stored in a cool, dark location. It is easy to work with and generally recommended for use with a trickle irrigation system.

### Chlorine Gas

Chlorine gas is very corrosive and poisonous and is not recommended for use unless a person is qualified to work with this chemical. Gaseous chlorine is usually only used on very large acreages where great amounts of chlorine are required. Sodium hypochlorite or calcium hypochlorite are recommended for use instead of chlorine gas for B.C. conditions.

### Calculating Chlorine Injection Rates

The injection rate of a chlorine solution will depend on the chlorine concentration of the chemical solution, the desired chlorine concentration in the water and the trickle system flow rate.

Commercial sodium hypochlorite (household bleach) usually has 12% available chlorine but is also available in 16% or 18%. Calcium hypochlorite is available as 70% available chlorine but requires pre-mixing since it is in granular form. The concentration of the mixed solution must therefore be determined before an injection rate can be calculated.

The formula used to calculate the chlorine solution injection rate is:

$$I = Q \times \frac{Cl}{1,000,000} \times 60 \times \frac{100}{(\text{bleach }\%)}$$

where I = chlorine injection rate in (gph)
Q = trickle system flow rate in (gpm)
Cl = desired residual chlorine concentrations (mg/L) of the water supply
Bleach % = chlorine concentration of solution to be injected in % of available chlorine.

## Example

Calculate the gph of solution required to inject 20 mg/L of chlorine into a trickle system with a flow rate of 50 gpm using a 12% sodium hypochlorite solution.

Q = 50 gpm
Cl = 20 mg/L
Bleach = 12%

$$I = 50 \text{ gpm} \times \frac{20 \text{ mg/L}}{1{,}000{,}000} \times 60 \times \frac{100}{12\%}$$

$$I = 0.5 \text{ gph}$$

If a treatment of 4 hours was desired, a 2 gallon container would be required.

## Acid Injection

The addition of acids to a trickle irrigation system water supply may be required to:

- reduce or eliminate the plugging of trickle emitters where calcium and/or magnesium carbonates form with water evaporation.
- reduce the water supply pH to make chlorination more effective.

Water supplies with Calcium (Ca) and Magnesium (Mg) concentrations greater than 50 mg/L and pH values of 8.0 or greater are susceptible to calcium or magnesium carbonate ($CaCo_3$ and $MgCO_3$) precipitates forming. Calcium or magnesium carbonates leave a white crusty deposit on the trickle system components when the water evaporates.

$$Ca^{+2} + CO_3^{-2} \longrightarrow CaCO_3$$

The addition of an acid neutralizes the carbonate ($CO_3^{-2}$) or bicarbonate ($HCO_3^-$) component leaving the calcium in solution. (Carbonates are generally not present unless the pH is greater than 8.3. Bicarbonate is present at pH values below 8.3.)

$$\begin{array}{cccccc} \text{acid} & + & \text{bicarbonate} & & \text{water} & + \text{ carbon dioxide} \\ H^+ & & HCO_3^- & \longrightarrow & H_2O & + \quad CO_2 \end{array}$$

### When is Acid Addition Necessary?

In the planning stages of the trickle irrigation system, the water source should be sampled and analyzed. A saturation index can be used to determine whether the irrigation water will precipitate or has the capacity to dissolve $CaCO_3$ or $MgCO_3$. A positive saturation index indicates calcium carbonates may precipitate.

Saturation index = pH - pHc

pH = actual measurement taken from water supply

pHc = p(Ca + Mg + Na + K) + p(Ca + Mg) + p($CO_3$ + $HCO_3$)

The values for pHc can be determined from table 7.6.

To determine the saturation index a water sample should be analyzed for Ca, Mg, K, Na, $HCO_3$, $CO_3$ and pH. All units except for pH must be expressed in meq/L (milliequivalents per liter). Table 7.5 can be used to convert mg/L into meq/L.

Table 7.5 Converting mg/L into meq/L

| Element | mg/L (ppm) | | meq/L |
|---|---|---|---|
| Ca | 20 | equals | 1 |
| Mg | 12 | | 1 |
| K | 39 | | 1 |
| Na | 23 | | 1 |
| $CO_3$ | 30 | | 1 |
| $HCO_3$ | 61 | | 1 |

Table 7.6 Calculation of pHc Terms

| meq/L | p(Ca+Mg+Na+K) | meq/L | p(Ca+Mg) | meq/L | p($CO_3$+$HCO_3$) |
|---|---|---|---|---|---|
| .5 | 2.11 | .05 | 4.60 | .05 | 4.30 |
| .7 | 2.12 | .10 | 4.30 | .10 | 4.00 |
| .9 | 2.13 | .15 | 4.12 | .15 | 3.82 |
| 1.2 | 2.14 | .20 | 4.00 | .20 | 3.70 |
| 1.6 | 2.15 | .25 | 3.90 | .25 | 3.60 |
| 1.9 | 2.16 | .32 | 3.80 | .31 | 3.51 |
| 2.4 | 2.17 | .39 | 3.70 | .40 | 3.40 |
| 2.8 | 2.18 | .50 | 3.60 | .50 | 3.30 |
| 3.3 | 2.19 | .63 | 3.50 | .63 | 3.20 |
| 3.9 | 2.20 | .79 | 3.40 | .79 | 3.10 |
| 4.5 | 2.21 | 1.0 | 3.30 | .99 | 3.00 |
| 5.1 | 2.22 | 1.25 | 3.20 | 1.25 | 2.90 |
| 5.8 | 2.23 | 1.58 | 3.10 | 1.57 | 2.80 |
| 6.6 | 2.24 | 1.98 | 3.00 | 1.98 | 2.70 |
| 7.4 | 2.25 | 2.49 | 2.90 | 2.49 | 2.60 |
| 8.3 | 2.26 | 3.14 | 2.80 | 3.13 | 2.50 |
| 9.2 | 2.27 | 3.90 | 2.70 | 4.0 | 2.40 |
| 11 | 2.28 | 4.97 | 2.60 | 5.0 | 2.30 |
| 13 | 2.30 | 6.30 | 2.50 | 6.3 | 2.20 |
| 14 | 2.32 | 7.90 | 2.40 | 7.9 | 2.10 |
| 18 | 2.34 | 10.00 | 2.30 | 9.9 | 2.00 |
| 22 | 2.36 | 12.50 | 2.20 | 12.5 | 1.90 |
| 25 | 2.38 | 15.80 | 2.10 | 15.7 | 1.80 |
| 29 | 2.40 | 19.80 | 2.00 | 19.8 | 1.70 |

From "Ideas in Soil and Plant Nutrition" (Joe Traynor).

### Example

A grower in the Fairview Heights Irrigation District wants to install a trickle irrigation system. Before proceeding with the planning and design he wants to assess whether acid injection will be required to treat calcium carbonate precipitate. Water analyses data for this district is shown in Table 7.7.

Conversion to meq/L from Table 7.5

pH = 8.1
$Ca^{+2}$ = 110 mg/L = 5.5 meq/L
$Mg^{+2}$ = 48 mg/L = 4.0 meq/L
$Na^{+1}$ = 26 mg/L = 1.1 meq/L
$K^{+}$ = 3 mg/L = 0.08 meq/L
$CO_3^{-2}$ = none = none
$HCO_3^{-}$ = 280 mg/L = 4.6 meq/L

Calculate the pHc terms in meq/L.

i) (Ca + Mg + K + Na) = 5.5 + 4.0 + 1.1 + .08 = 10.7 meq/L
ii) (Ca + Mg) = 5.5 + 4.0 = 9.5 meq/L
iii) $(CO_3 + HCO_3)$ = 0 + 4.6 = 4.6 meq/L

From Table 4.6

i) p (Ca + Mg + K + Na) = p (10.7) = 2.28
ii) p (Ca + Mg) = p (9.5) = 2.32
iii) p $(CO_3 + HCO_3)$ = p (4.6) = 2.34

pHc = 2.28 + 2.32 + 2.34 = 6.94

Saturation Index = pH - pHc = 8.1 - 6.94 = 1.16

The positive value indicates that $CaCO_3$ and $MgCO_3$ will precipitate.

For most situations the buildup of $CaCO_3$ is very gradual over a long period of time. In these instances a periodic dosage of an acid may be all that is required. For most cases lowering the water pH to 6.5 for 24 hours will be sufficient to treat any precipitation buildup that may have occurred. The acid can then be injected before the filtration system. If the emitters are severely plugged the trickle lines may have to be filled with water acidified to pH 2. In this case the acid must be injected after the filtration system to prevent corrosion of any metallic parts. The pH 2 water should be left in the lines for about one hour and then the entire system completely flushed.

**Calculating the Amount of Acid Required**

To calculate the amount of acid required to adjust the irrigation water to the desired pH a titration curve will provide an acid factor.

Acid factor is the milliequivalents of acid per litre of water required to lower pH to the desired level.

Table 7.7 provides acid factors to achieve a pH of 6.5 for the irrigation districts shown.

Table 7.8 provides information on the amount of acid required to achieve the pH desired based on the acid factor.

Table 7.7 Irrigation District Water Analyses

| Irrigation District | pH | Ca mg/L | Mg mg/L | Na mg/L | K mg/L | $CO_3$ mg/L | $HCO_3$ mg/L | Acid Factor (to achieve pH 6.5) |
|---|---|---|---|---|---|---|---|---|
| Cawston | 7.5 | 65 | 12 | 14 | 3 | - | 135 | 0.98 meq/L |
| Fairview Heights | 8.07 | 110 | 48 | 26 | 3 | - | 280 | 2.02 meq/L |
| Osoyoos | 7.8 | 38 | 10 | 10 | 3 | - | 140 | 1.04 meq/L |
| SOLID | 8.2 | 35 | 8 | 13 | 3 | - | 140 | 0.98 meq/L |
| Summerland Garnet Vy. | 8.0 | 55 | 8 | 12 | 3 | - | 17 | 0.20 meq/L |
| Lakeview | 8.0 | 35 | 6 | 6 | 2 | - | 149 | 1.14 meq/L |
| Wood Lake | 7.5 | 80 | 27 | 35 | 7 | - | 30 | 0.20 meq/L |

Note:

The Irrigation Districts listed above are suspected of having $CaCO_3$ precipitate problems. Values shown are maximums that have been measured over a period of four years. It is recommended that each grower analyze his own water supply to refine the figures in the above table.

**Table 7.8 Amount of Acid Required to Lower Water pH**

| Acid Factor | Amount of Acid Required per 1000 Gallons of Water<br>Sulfuric Acid<br>$H_2SO_4$ (95%) | <br>Hydrochloric Acid<br>HCl (36%) |
|---|---|---|
| 0.5 meq/L | 0.04 litres | 0.15 litres |
| 1.0 | 0.08 | 0.30 |
| 2.0 | 0.19 | 0.61 |
| 4.0 | 0.41 | 1.29 |
| 6.0 | 0.60 | 1.90 |
| 8.0 | 0.83 | 2.54 |
| 10.0 | 1.06 | 3.18 |
| 15.0 | 1.55 | 4.73 |

The formula to calculate the acid injection rate is:

$$Ia = \frac{A \times Q \times 60}{1000}$$

Where Ia = acid injection rate L/hr
A = amount of acid(litres)/1000 gallons of water
Q = trickle irrigation system flow rate (gpm)

Example

A grower in Fairview Heights Irrigation District has a trickle system with a 50 gpm flow rate. A titration analysis indicates that an acid factor of 2.02 meq/l is required to lower the water pH to 6.5 (Table 4.7 provides this information for a few irrigation districts.) The grower wishes to lower the water pH to 6.5 for a 12-hour period. How much 95% sulfuric acid is required?

Q = 50 gpm

A = 0.19 litres/1000 gallons of water from Table 4.8
(acid factor is 2.02 meq/L)

$$Ia = \frac{0.19 \text{ litres}}{1000 \text{ gallons}} \times 50 \text{ gpm} \times 60 = 0.57 \frac{\text{litres}}{\text{hour}}$$

To inject for 12 hours will require:

$$0.57 \frac{\text{litres}}{\text{hour}} \times 12 \text{ hours} = 6.8 \text{ litres}$$

If a severe $CaCO_3$ plugging problem exists, a stronger dosage of acid injection may be required. In these situations it is suggested that water acidified to pH 4.5 is left to sit in the lines for one hour. The entire system should then be thoroughly flushed until the water runs clear. A check of the emitter flow rates before and after treatment will indicate whether an improvement in flow rate has been achieved.

### Titration Analysis

Another method of determining the amount of acid required to achieve a pH level is as follows:

- fill a 40 gallon drum with water
- add a small amount of acid (10 ml) and mix thoroughly
- measure the pH level
- continue to add small amounts of acid until the pH level is reached
- the A term in the acid injection formula can then be determined
- once the A term has been determined the acid injection rate can be calculated.

### Acid Selection and Method of Application

Acids are made available in various degrees of strength and purity. Before selecting and applying any acid the following points should be kept in mind:

i) When injecting acids for durations longer than one hour, the pH level should not be reduced below 6.5. Excessive acidification can be corrosive to pipes, fittings and will eventually harden rubber valve seats.

ii) All acids are very corrosive when concentrated. Acids must therefore be injected into the irrigation systems at a point that allows suitable dilution with water before contacting metal components of the irrigation system.

iii) If the water is acidified to a level below pH 4.0, the acid must be injected downstream of any metal components.

iv) Acid should always be added to water, not vice versa. **An explosion could occur if water is added to an acid.**

v) By selecting a mineral acid, such as phosphoric, nitric, etc., some fertilizer benefits can also be achieved. (75% phosphoric acid is 0-52-0 in fertilizer terminology. Phosphoric acid is also the least dangerous acid to handle.)

vi) Mixing an acid with other fertilizer salts prior to injection can create a very corrosive solution. Premixing these in a large tank of water avoids concentrated solutions which will reduce this problem. Also, by injecting acids and fertilizers separately (but still simultaneously, i.e., two injectors) the mixing will occur in a diluted state and will therefore be less corrosive.

# VIII FERTILIZER AND CHEMICAL INJECTION

Trickle irrigation systems are ideal for precise applications of fertilizers, nematocides and other chemicals. Advantages of applying fertilizers and other chemicals through a trickle irrigation system include:

- the high application efficiencies of these systems ensure even and uniform application of the chemical
- since the chemicals are applied directly to the plant's root zone, maximum availability and efficiency of chemical application can be obtained
- labour, machinery and fuel savings are achieved over conventional chemical application methods
- nutrients can be applied during the growing season with precalculated amounts and frequencies to meet the demands at various growing stages. This is especially important for chemicals that are susceptible to leaching loss, which may cause late season nutrient deficiency.

To reduce plugging and chemical problems the following points should be considered when applying nutrients or chemicals through a trickle irrigation system:

- chemicals must be readily soluble
- when two or more chemicals are injected at one time they must not form a precipitate in solution
- chemicals injected must not react with elements in water after injection
- chemicals must not corrode components of the trickle system
- chemicals should always be injected before the filtration unit

To ensure compatability of the chemical to be injected with the irrigation water, a simple test should be conducted before injecting the chemical. Add a small amount of the chemical to be injected to a jar filled with water from the irrigation system. Ensure that the concentration will be slightly higher than the solution anticipated in the system. Shake well and leave for 24 hours. If a reaction has occurred during this period the chemical is not recommended for injection.

## 8.1 BACKFLOW PREVENTION REQUIREMENTS

A cross connection is defined as any connection or structural arrangement between a potable water system and any non-potable water system or chemical source through which backflow can occur. Any temporary or permanent devices through which backflow can occur are considered cross connections.

A direct connection between a potable water system and a non-potable system is subject to backflow conditions due to either backsiphonage or backpressure. Backsiphonage is caused by low pressure or a reduced pressure in the supply piping. Backpressure occurs when the user system is at a higher pressure than the potable water supply system. In a trickle irrigation system backpressure can be caused by either elevation differences in the system or chemical injection pumps.

**The injection of fertilizers and chemicals into a trickle system is considered to be a severe hazard to a potable water system.** An approved backflow preventor must therefore be installed on trickle systems injecting chemicals. Three types of backflow preventors may be considered.

## Pressure Vacuum Breaker

The pressure vacuum breaker (PVB) has an atmospheric vent valve which is internally loaded by a spring (see figure 8.1 and 8.2). A PVB must be installed (30.5 cm) above the highest outlet on the non-potable water system. A PVB can only be used if the chemical added is chlorine for algae control. PVB are effective against backsiphonage only and cannot be used if injector pumps or booster pumps are connected into the trickle irrigation system.

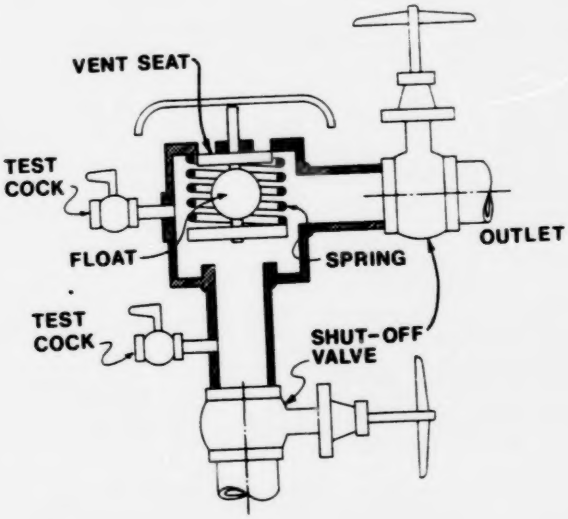


Figure 8.1 **Pressure Vacuum Breaker**

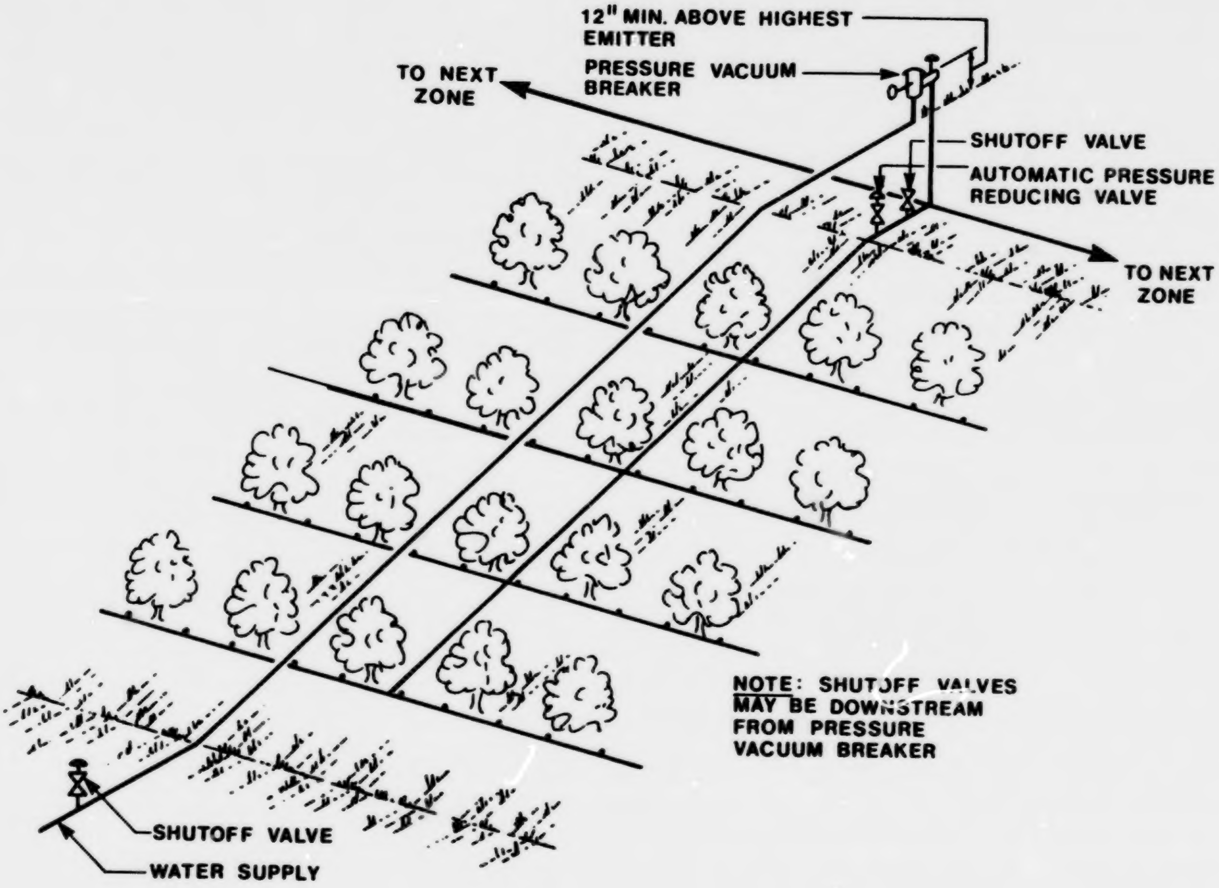

12" MIN. ABOVE HIGHEST EMITTER
PRESSURE VACUUM BREAKER
TO NEXT ZONE
SHUTOFF VALVE
AUTOMATIC PRESSURE REDUCING VALVE
TO NEXT ZONE
NOTE: SHUTOFF VALVES MAY BE DOWNSTREAM FROM PRESSURE VACUUM BREAKER
SHUTOFF VALVE
WATER SUPPLY

Figure 8.2 Pressure Vacuum Breaker Installation

## Double Check Valve Assembly

A double check valve assembly (DCVA) consists of two approved check valves, internally loaded either by a spring or weight, which are installed as a unit between two tightly closed shut-off valves. A DCVA is effective against backflow caused by backpressure or backsiphonage. The DCVA should be installed at the inlet to the trickle irrigation system.

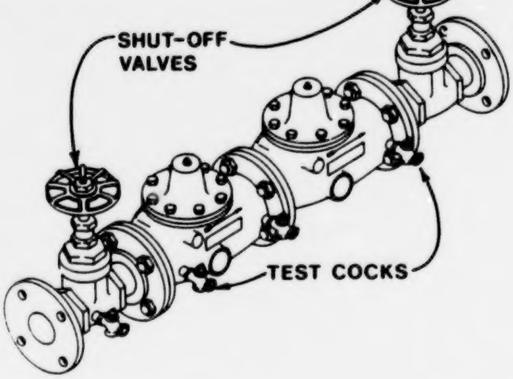


Figure 8.3 Double Check Valve Assembly

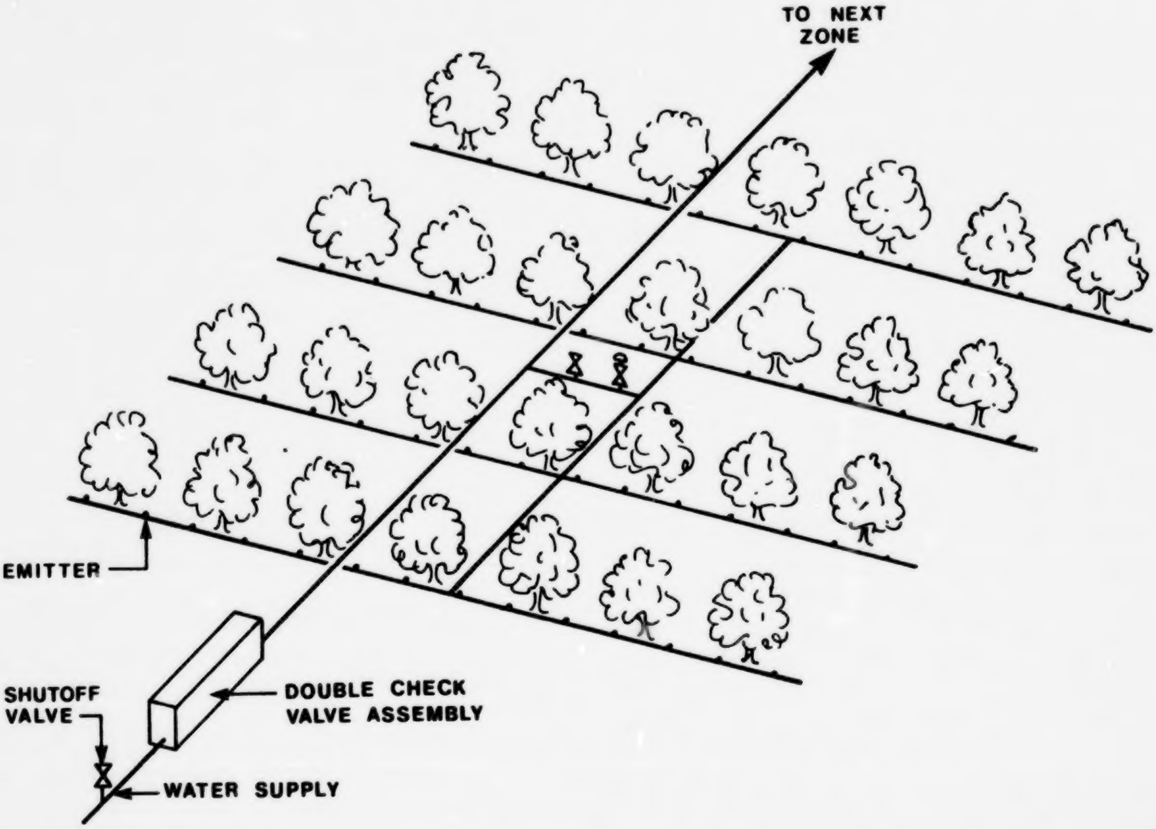


Figure 8.4 DCVA Installation

## Reduced Pressure Principle Backflow Prevention Device

A reduced pressure principle backflow device (RPBD) consists of two independently acting, internally loaded check valves separated by a reduced pressure zone. The device should be installed as a unit between two tightly closing shut-off valves. The RPBD is effective against backflow caused by backpressure and backsiphonage and is used in situations which are considered to be very hazardous.

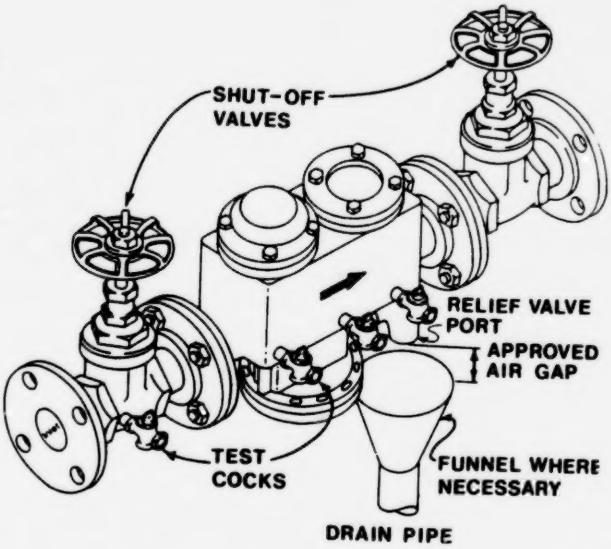


Figure 8.5 Reduced Pressure Backflow Prevention Principle Device

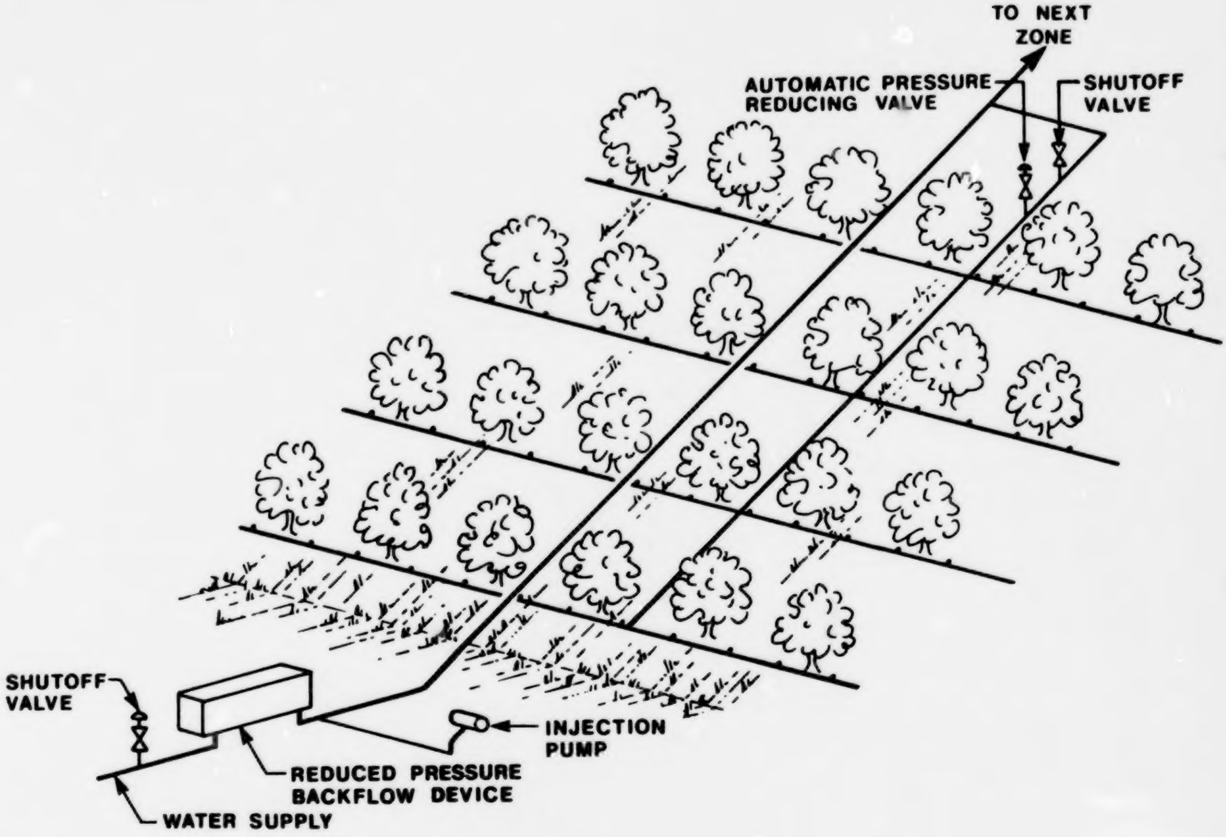

TO NEXT ZONE
AUTOMATIC PRESSURE REDUCING VALVE
SHUTOFF VALVE
SHUTOFF VALVE
INJECTION PUMP
REDUCED PRESSURE BACKFLOW DEVICE
WATER SUPPLY

Figure 8.6 RPBD Installation

## 8.2 CHEMICAL INJECTION METHODS

Trickle irrigation systems can utilize numerous injection methods including ratio feeders, diluters, injector pumps, venturi injectors and pump suction line injectors. Factors which affect the type of injection principle used include cost, available power source, reliability and ease of regulating the injection rate.

### Injector Pumps

Injector pumps can be either electrically-powered or water-driven. They have greater precision than any of the other injection methods but are more costly.

The injector pump provides variable speed drives to allow for a wider range of injection rates. An injector pump is capable of supplying the same concentration of chemical at a constant rate for the required duration. The pump must be made of non-corrosive material due to the nature of the chemicals injected.

An electric injector pump (figure 8.7) is capable of continuing to inject chemicals once the irrigation system has been shut down. Careful monitoring during chemical application is therefore always important. This problem can be somewhat overcome by application on a batch-per-zone basis.

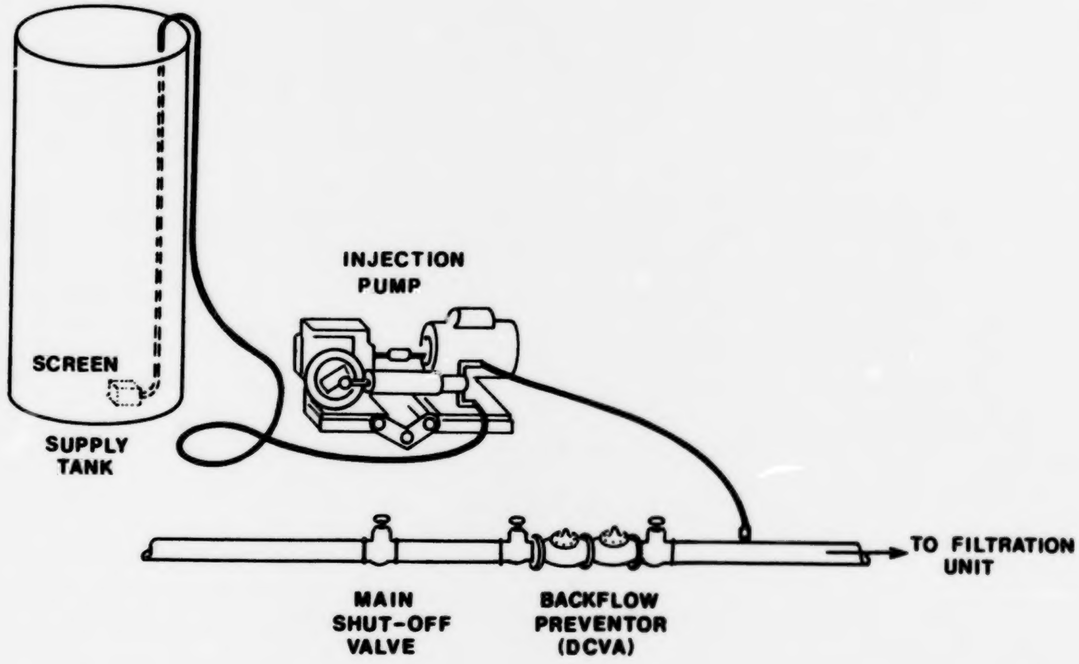


Figure 8.7 Electric or Gas Injector Pump

Water-powered injector pumps are available in turbine (impeller) or piston drive. Piston-operated pumps use a small amount of irrigation water to drive the piston. The drive water is expelled (usually three times the quantity of the injected solution). The injection rate is set by controlling the amount of water going to the drive piston. Piston-drive units do not reduce the irrigation system pressure.

A turbine water-driven injector does not expel water but does utilize some of the irrigation system supply pressure. The irrigation system design must take this into account to ensure that adequate pressure is available to operate both the injector and the system. These types of injectors are available in single and double head models.

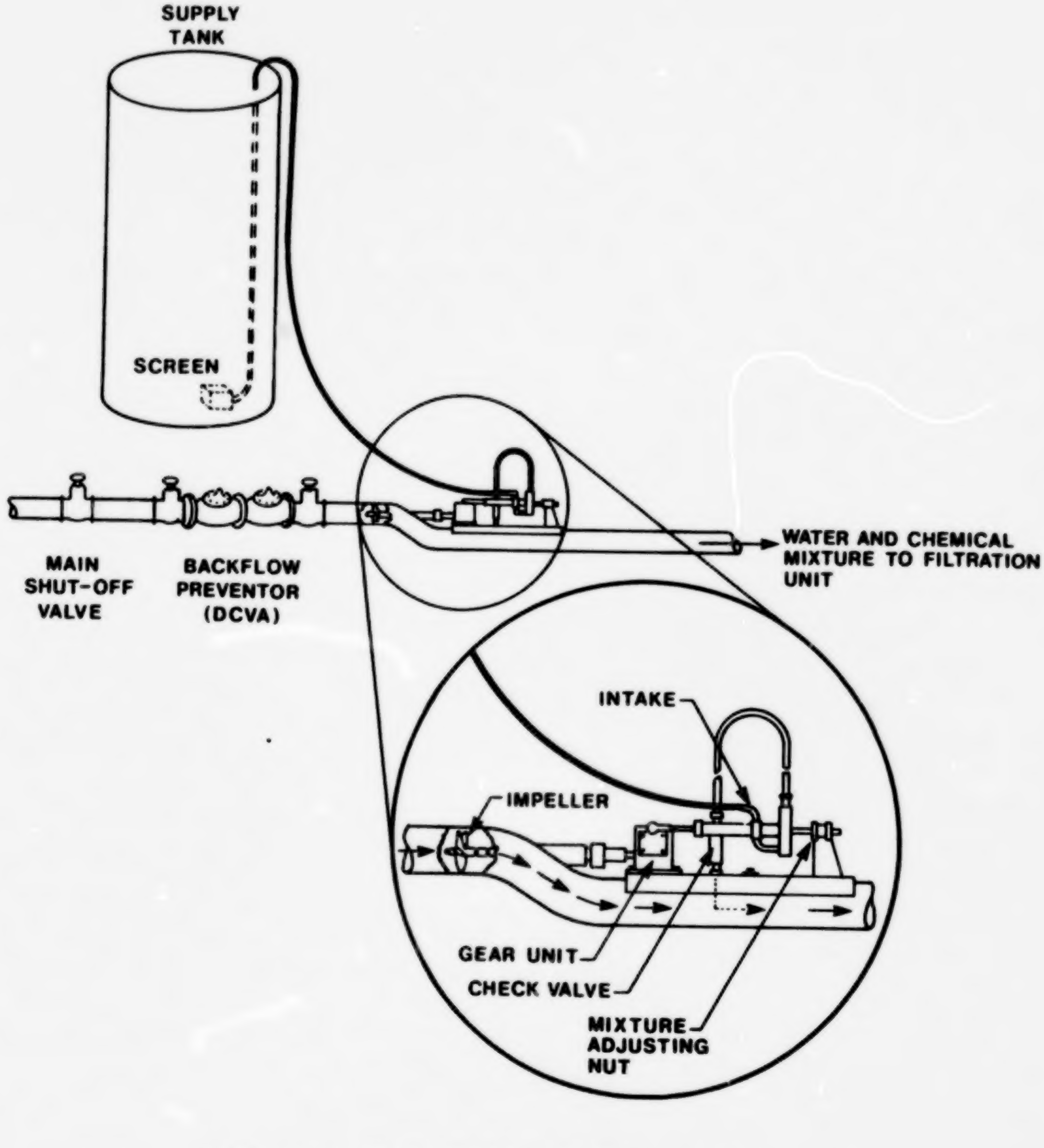


Figure 8.8 Water Turbine-Driven Injector

## Venturi Injectors

Venturi injectors operate on the principle that a pressure drop accompanies the change in water velocity as it passes through a constriction. Atmospheric pressure forces the chemical into the line at this reduced pressure zone. These types of systems are not effective for low pressure situations as they have a significant head loss across them. Venturi systems are usually installed parallel to the irrigation system supply lines. Table 8.1 indicates typical injection rates that can be achieved with a venturi injection system.

Table 8.1 Venturi Injection Capacities

| Model No. | Injector Size | Flow Thru Injector @ 40 psi | Injection Capacity gph |
|---|---|---|---|
| 283 | 1/2 MNPT | 0.5 GPM | 6 |
| 384 | 1/2 " | 1.7 " | 9 |
| 384-X | 1/2 " | 1.7 " | 33 |
| 484 | 1/2 " | 3.2 " | 17 |
| 584 | 3/4 " | 5.8 " | 25 |
| 885-X | 1 " | 10 " | 135 |
| 878 | 1 " | 10 " | 50 |
| 1078 | 1 " | 15 " | 75 |
| 1583 | 1 1/2 MNPT or Hose Barb | 32 " | 180 |
| 1584 | 1 1/2 MNPT | 56 " | 120 |
| 2081 | 2 MNPT or | 90 " | 500 |
| 2083-B | 2 MNPT or Hose Barb | 26 " | 1200 |

From Mazzei Injector Corporation

## Pressure Differential Injection

Pressure differential injectors or a diluter, is a pressurized tank installed in parallel to the irrigation line. The inlet and outlet to the tank are connected to the mainline at two different pressures, usually on either side of a pressure reducing valve. (See figure 8.10.) The difference in pressure is sufficient to create a flow of water through the tank. The chemical in the tank is slowly diluted until it has all been applied. This type of injection is usually used where a gross chemical application is required without consideration to chemical concentration. A new charge of chemical must be put into the tank everytime a new zone is irrigated. This type of injection works well for small systems of up to 40 gpm and are relatively trouble-free and inexpensive.

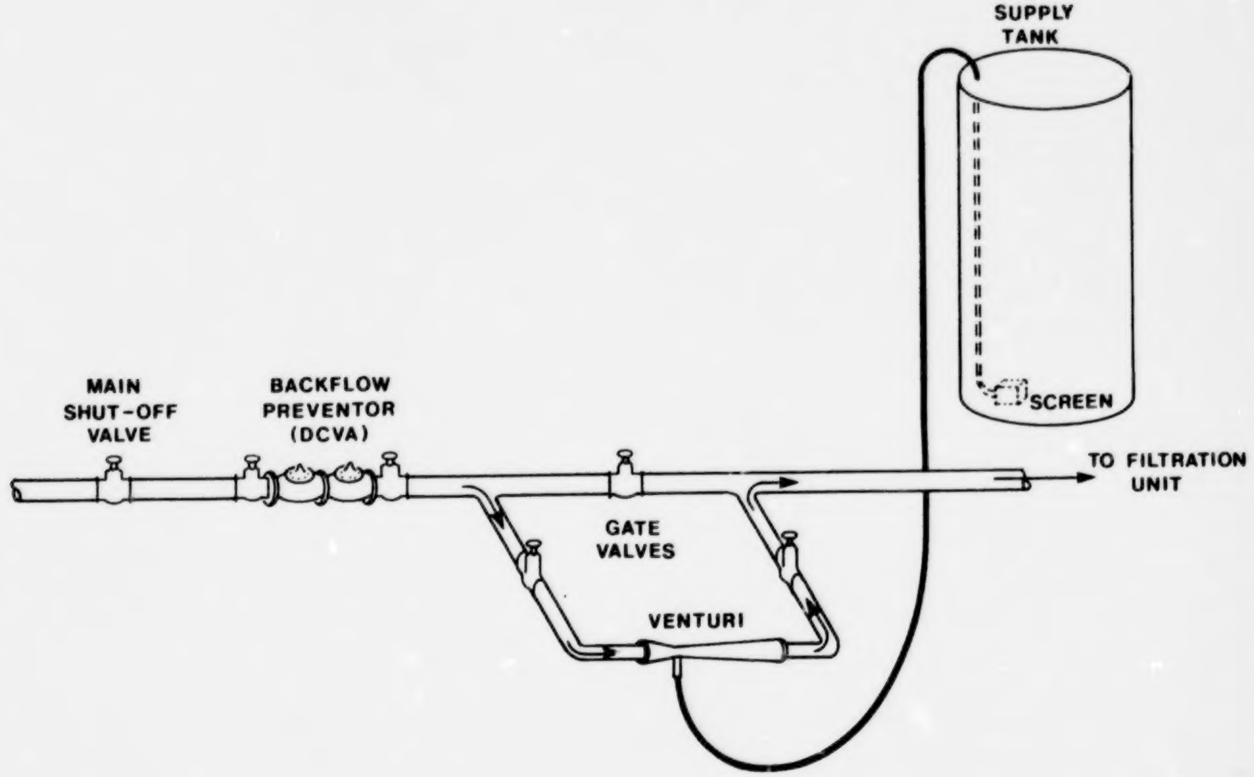


Figure 8.9 Venturi Injector

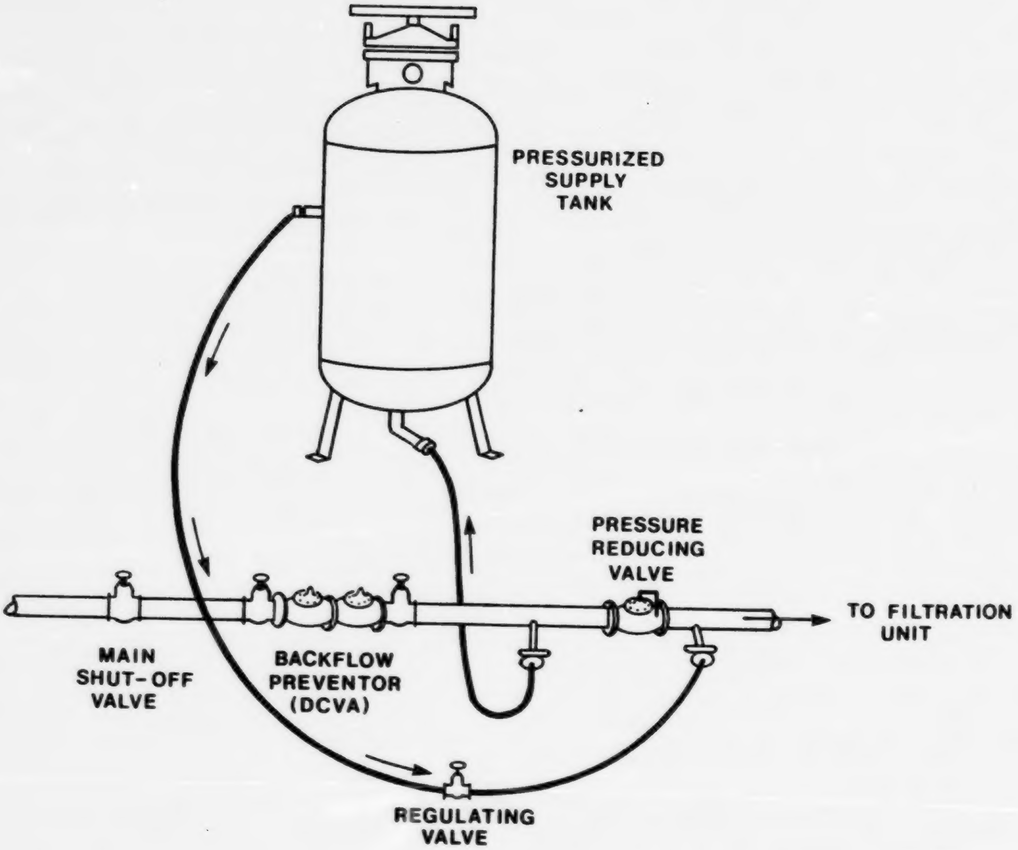


Figure 8.10 Pressure Differential Injection

A diluter with a diaphragm to separate incoming water from fertilizer is also available and is used primarily in small greenhouses.

## 8.3 FERTILIZER APPLICATION THROUGH TRICKLE IRRIGATION SYSTEMS

Applying fertilizers through a trickle irrigation system reduces labour and energy costs, improves efficiency and makes it possible to time nutrient applications in accordance with crop demand. Care should be taken to prevent emitter clogging, system/component corrosion and ensure uniform distribution of applied fertilizers in the plant's root zone.

Trickle irrigation systems should be designed to provide high enough flow rates so that injected chemicals are distributed uniformly throughout the distribution lines. Uniformity tests on system discharge rates performed in the Fraser Valley (Keng et al, 1985) revealed satisfying results when methylene blue dye solution was used to simulate soluble fertilizers. Fertilizer distribution in the soil, however, is more complicated. Once in the soil, fertilizers undergo ion exchange and fixation with the soil minerals, microbial transformation, leaching, denitrification, etc. This will be discussed in the subsequent sections.

System corrosion has been minimized with the use of all plastic components. Precipitation around the orifice of emitters, however, still needs constant attention in order to maximize the life expectancy of the system. For most chemical solutions, precipitation may occur when a change of pH, temperature, or pressure occurs.

High bicarbonate and/or iron concentrations in some irrigation waters may react with the fertilizers and cause precipitation of insoluble calcium or iron compounds. Certain bacteria can also fix iron as a by-product of metabolism and produce slime or jell-like material inside the systems. Algae growth may be encouraged by nutrients in the water. Special maintenance procedures such as chlorination, adding algaecides, bactericides and pre-treating water with chelating agents (to deactivate iron) may be needed when performing fertigation or chemigation. (See section 7.3).

### Nitrogen Fertigation

The injection of nitrogen fertilizer into a trickle system has a history almost as long as trickle irrigation itself. Most commercially available forms of nitrogen fertilizers are readily soluble in water and cause few precipitation or clogging problems. Nitrogen is the most commonly deficient nutrient for crop production in British Columbia. Concentrated liquid nitrogen fertilizer is recommended for trickle fertigation. In areas where liquid fertilizer is not available, homemade fertilizer solutions from dissolved dry fertilizers may be injected into the trickle system. Careful filtration is required since inert conditioners used as anti-caking agents in some solid fertilizers may cause serious clogging. Nitrogen remaining in trickle systems for a prolonged time could create clogging by microbial growth. Therefore, thorough flushing with fresh irrigation water after every chemical injection is essential.

Urea (46-0-0) is a highly soluble nitrogen fertilizer. In water solutions it acts as a neutral molecule and does not ionize. Urea is sometimes mixed with ammonium nitrate (34-0-0) to form a concentrated liquid for trickle fertigation use. Such mixtures cause only slight pH shifts in the irrigation water. Ammonium sulfate (21-0-0) and other nitrate salts, such as calcium nitrate (15-0-0), are relatively soluble and do not cause a large pH change in irrigation water, therefore, are also suitable for fertigation use.

Anhydrous ammonia (82-0-0) and aqua-ammonia (24-0-0), when injected into the irrigation water, may volatilize as gaseous ammonia and result in lower fertilizer efficiency. Since ammonia will increase the pH of fertigation solutions, calcium and magnesium will precipitate. The use of either anhydrous ammonia or aqua-ammonia for trickle fertigation is not a common practice in Canada.

The high frequency of water applications in trickle irrigation systems creates an almost continuously outward flow pattern immediately below the trickle emitters, causing leaching in this zone. As a result, the electrical conductivity is relatively low near the emitter but becomes high at a zone where a balance between irrigation water input and moisture depletion through root suction is reached. This zone of high conductivity contains a concentration of nutrients which is suitable for crop root system development.

Nitrate-nitrogen, a negatively charged ion or anion, moves freely with irrigation waters and tends to accumulate at the periphery of the wetted soil volume when repeated irrigations are performed. Therefore only a portion of the applied fertilizer is within easy reach of active root systems and the unused nitrogen is subject to leaching loss.

Urea molecules, like nitrate-nitrogen, tend to stay in the soil solution and move in the same direction as the irrigation water. However, urea undergoes enzyme hydrolysis with an enzyme in the soil and forms ammonium. Ammonium, a positively charged ion, or cation, is attracted by negative charges on clay minerals and becomes immobile in soil. Therefore, urea placement in the root zone may be achieved with proper irrigation water management. Accurate placement of trickle fertigated urea fertilizer depends on the emitter discharge rate, irrigation frequency, the exchange capacity and physical properties of the soil.

Ammonium fertilizers applied with irrigation tend to concentrate immediately below the emitter which is different from nitrate and urea fertilizers. This is because ammonia or ammonium is immobilized in the soil by the cation exchange process discussed previously. In situations where the surface soil temperature is high and particularly combined with alkaline soil conditions (pH 7 to 8), ammonium accumulated at the surface is highly susceptible to gaseous loss via volatilization. This can be reduced by decreasing evaporation loss using plastic or other mulch systems.

## Potassium Fertigation

There seem to be few problems of precipitation or clogging when potassium is injected into irrigation water. Most commercially available potassium fertilizers, such as muriate potash, potasium-sulfate and potassium nitrate, are all highly soluble in water regardless of its pH.

Potassium is absorbed in the soil by cation exchange similar to ammonium. However, since the potassium ion ($K^+$) has a lower affinity for the soil colloid surface than does the ammonium ion ($NH_4^+$), considerable movement of potassium through the soil can be achieved when applied through trickle irrigation systems.

## Phosphorus Fertigation

Several precautions should be taken when applying phosphorus fertilizer through trickle irrigation systems. The most common source of P fertilizer, treble-super phosphate (TSP) (0-45-0), is not recommended for fertigation, despite the fact that it is legally classified as being water soluble. Mono-calcium phosphate, a main constituent of TSP, changes spontaneously to dicalcium phosphate in solution and precipitates readily.

Ammonium phosphates, such as ammonium phosphate sulfate (16-20-0), monoammonium phosphate (11-48-0) and diammonium phosphate (16-46-0), are highly water soluble and are being sold commercially as phosphorous sources for trickle fertigation. Phosphoric acid and organic phosphate compounds such as glycerophosphate, have also been applied successfully through trickle irrigation systems.

The main limitation of phosphorous in fertigation is that phosphorous may react with calcium and/or magnesium and form insoluble dicalcium phosphate or dimagnesium phosphate. When irrigation water has a high content of calcium and magnesium, phosphorous application via trickle systems should be avoided. If fertigation is attempted with irrigation water high in calcium or magnesium, the water pH should be kept low when phosphorus is injected to ensure that the calcium/magnesium salts remain soluble. A brief injection of acid, using either sulfuric acid or hydrochloric acid, immediately after the phosphorus injection cycle will reduce the probability of precipitation. Since acidic solutions will corrode metal parts, only plastic components should be used downstream of the injection inlet. (See Section 7.3).

Phosphorous is readily absorbed and precipitated in most soils and is generally considered immobile when applied topically at normal fertilization rates. For this reason phosphorus has not usually been recommended for application through an irrigation system. However, when a highly concentrated phosphorus solution is applied with trickle irrigation to a small soil surface, movement in the soil as far as 20 cm horizontally and 30 cm vertically from emitters has been observed. Such movement probably resulted from phosphorus saturating the soil near the emitters and the excess phosphorus moved by mass flow with the irrigation water.

Table 8.2 provides additional information on fertilizer compositions which may be helpful in selecting fertilizers.

## Micronutrients

Due to the small quantity required by crops, foliage spray of needed micro nutrient elements is the most often recommended means of application. Chelates and/or sulfate salts of micronutrient elements, such as iron, zinc, copper and manganese, are recommended when applied by trickle irrigation. Chelates are water soluble and do not cause precipitation and clogging problems. However, some growers in the U.S. have encountered clogging problems when they use zinc sulfate in trickle systems. The high cost of chelates present another limitation.

The major concern of micro nutrient fertigation is the high affinity of the cationic micronutrients to the soil matrix. The fertigated micro nutrient elements may not move far enough to achieve proper placement in the root zones.

## Pesticides

Herbicides, fungicides and several kinds of soil fumigants have been applied through trickle irrigation systems with various degrees of success. Herbicides tend to be absorbed on the soil particles and are not adequately distributed for effective weed control. Most herbicides break down rather quickly in moist soil making them ineffective. Mist, rather than drip emitters, may be more suitable for herbicide application. Experimental applications of Furadan and other post planting nematocides through trickle irrigation systems achieved excellent nematode control even with application rates less than recommended standard methods.

The use of trickle systems for pesticide application to control soil pathogens depends on the chemical nature of the particular pesticide as well as the special need of crops at various growth stages. Several trickle pestigation research projects are currently being conducted in various parts of the world which may result in decreased production costs and reduced pollution hazards for densely populated agricultural areas such as south coastal British Columbia.

**Table 8.2** Fertilizer Composition

| Solution Product | Formula | Nutrient Value | *Equivalent Acidity |
|---|---|---|---|
| Ammonium Nitrate | $NH_4NO_3$ | | |
| Liquid | | 20% | |
| Dry | | 33% N | 62 |
| Ammonium Phosphate | $NH_4H_2PO_4$ | | |
| Liquid | | 8% N 24% $P_2O_5$ | |
| Dry | | 11% N 48% $P_2O_5$ | 58 |
| Ammonium Sulphate | $(NH_4)_2 SO_4$ | 21% N | 110 |
| Dry | | 24% S | |
| Urea | $CO (NH_2)_2$ | 45% N | 71 |
| Calcium Nitrate | $Ca (NO_3)_2$ | 15.5% N | -20 |
| Aqua Ammonia | | | |
| Liquid | $NH_4 OH$ | 20% N | 36 |
| Potassium Chloride | | | |
| Dry | KCl | 60% $K_2O$ | neutral |
| Potassium Nitrate | $KNO_3$ | 45% $K_2O$ | 23 |
| Dry | | 13% N | |
| Potassium Sulphate | | | |
| Dry | $K_2SO_4$ | 50% $K_2O$ | neutral |
| Phosphoric Acid | | | |
| Liquid | $H_3 PO_4$ | 50% $P_2O_5$ | 110 |
| Calcium Ammonium Nitrate | | | |
| Liquid | 11.6% CA $(NO_3)_2$<br>5.4% $NH_4 (NO_3)$ | 17% N | |
| Potassium Ammonium Phosphate | | | |
| Liquid | $KNH_4HPO_4$ | 15%N<br>15%P<br>6%K | |

* Pounds of $CaCO_3$ per 100 pounds of fertilizer required to neutralize.

From James Hardie Irrigation Design Manual, and Sprinkler Irrigation Text, 4th Edition.

## Calculating Chemical Injection Rates

Injection with a metering pump is the most common and precise fertigation method. The injection rate depends on the concentration of the liquid to be injected and the quantity of materials to be applied during each irrigation. The following equation may be used for calculating the rate of injection:

$$Ic = \frac{Qc \times A}{C \times T}$$

Where : Ic = Rate of chemical injection (L/min)

Qc = Quantity of chemical to be applied per irrigation cycle (kg/ha)

C = Concentration of injected solution (kg/L)

T = Total time of injection (min)

A = Area (ha)

### Example 1

A farmer has a trickle irrigation system with 2.5 acre zones. There are a total of 6100 tomato plants per acre. He plans to apply the recommended 34 kg/ha side-dress nitrogen through the trickle irrigation system in five equal weekly applications when the first fruit begins to set. A concentrated solution of urea and ammonium nitrate containing 30% or 0.3 kg/litre nitrogen is recommended for trickle fertigation. The duration of each irrigation cycle is 2 hours in order to apply sufficient water to the plant. How should he perform nitrogen fertigation?

In order to allow sufficient time to flush the trickle system after each fertilizer injection, and also to place the fertilizer added into the active root zone, a 40 minute injection time is chosen and the metering pump is turned on 20 minutes after irrigation begins. After injection, irrigation continues for another 60 minutes (a total of 2 hours).

$$Qc = \frac{34 \text{ kg/ha}}{5 \text{ weeks}} = 6.8 \text{ kg/ha/week}$$

$$C = 0.3 \text{ kg/L}$$

$$T = 40 \text{ min}$$

$$A = 2.5 \text{ ac} \times \frac{1 \text{ ha}}{2.47 \text{ ac}} = 1 \text{ ha}$$

$$Ic = \frac{Qc \times A}{C \times T} = \frac{6.8 \text{ kg/ha} \times 1 \text{ ha}}{0.3 \text{ kg/L} \times 40 \text{ min}} = 0.57 \text{ L/min}$$

Therefore, the injection rate for the 2.5 acres (1 hectare) field of tomatoes is 0.57 litres per minute.

Example 2

Determine the quantity of nematocide and water to be applied in a 150 ft raspberry row. A portable 12" x 60" Bi-Wall trickle system with a discharge rate of 0.8 gpm/150 ft (Figure B.4) is used. A concentration of 5-10 ppm of carbofuran in the root zone is required to control the nematode effectively. Furadan is usually available at a concentration of 48% carbofuran.

Step 1. Calculate the volume of soil to be treated. The soil volume to be treated for nematodes will generally be within the top foot of soil. The most active part of a raspberry's root system lies within this regime. Assume a soil volume 1.5 ft radius from the emitter discharge point.

The total wetted soil volume =

$$\frac{\pi r^2}{2} \times \text{row length (ft)} = \frac{\pi (1.5)^2}{2} \times 150 \text{ ft} = 530 \text{ ft}^3$$

Step 2 Calculate amount of Furadan needed:

The field capacity water content of this particular raspberry soil is 26% by volume. In the wetted zone, there is 530 $\text{ft}^3$ x 26% = 138 $\text{ft}^3$ of water.

Amount of Furadan (48%) to ensure a 10 ppm soil solution concentration is:

$$F = \frac{10 \text{ ppm} \times 138 \text{ ft}^3}{1{,}000{,}000 \times 0.48} = 0.0029 \text{ ft}^3 = 0.08 \text{ L}$$

Step 3 Calculate the amount of irrigation water needed:
Assume the root zone soil water content before irrigation was 22% by volume. The additional water therefore needed to bring soil water content to field capacity is:

$$530 \text{ ft}^3 \times (26\% - 22\%) = 21.2 \text{ ft}^3$$
$$= 159 \text{ gal}$$

The Bi-Wall 12" x 60" used in this example will apply 0.8 gpm/150 ft.
The application time needed to apply 159 gallons to the 150 ft raspberry row will be:

$$\frac{159 \text{ gal/150 ft row}}{0.8 \text{ gpm/150 ft row}} = 200 \text{ min}$$

Therefore, 0.08 Liters of Furadan 48% over a 200 minute period should be applied for this example.

Note: Knowledge of wetting patterns and water content of the soil to be treated is needed for effective pesticide application by a trickle system.

# IX MONITORING SOIL MOISTURE

The trickle irrigation concept is to frequently replenish the soil water evaporated and consumed by the crop during the growing season. A crop irrigated with a trickle irrigation system will require less water on an annual basis than the same crop irrigated by conventional sprinkler or flood systems. Reduction in crop water use occurs with trickle irrigation systems due to:

- reduced percolation losses
- high irrigation application efficiencies
- decreased evaporation due to a reduced wetted area. Since a trickle irrigation system does not irrigate the center of row panels, and cover crops are allowed to die back, the overall evapotranspiration is reduced.

A trickle irrigation system, like any other irrigation system is designed to match the peak irrigation requirement during the growing season. Plant water requirements throughout the growing season will vary substantially from the peak requirement.

To accurately schedule irrigation applications with a trickle system requires monitoring of the soil moisture. A grower converting from sprinkler to trickle irrigation may experience difficulty in scheduling the trickle system due to the concept differences. It is recommended that growers use some method of soil moisture measurement.

## 9.1 SOIL MOISTURE MEASUREMENT METHODS

The following soil moisture measurement methods are suggested for trickle irrigation systems.

### Soil Feel Test

A soil auger or soil tube can be used to obtain a soil sample. Samples should be obtained starting from a depth of 8" - 9" to the bottom of the effective root zone. See figure 9.1 for soil moisture measuring locations for tree fruits. Squeeze a handful of soil tightly. If it forms a ball, bounce it three times lightly in your palm. The relative soil moisture content can be rated as follows:

1. Air dry or almost so.
2. Moist but not wet enough to form a ball.
3. Barely holds a ball when bounced lightly. Cracks a little when bounced harder.
4. Forms a tight ball.
5. Water can be squeezed out of it.

For a trickle irrigation system the soil moisture should be maintained at level 4 to obtain optimum results.

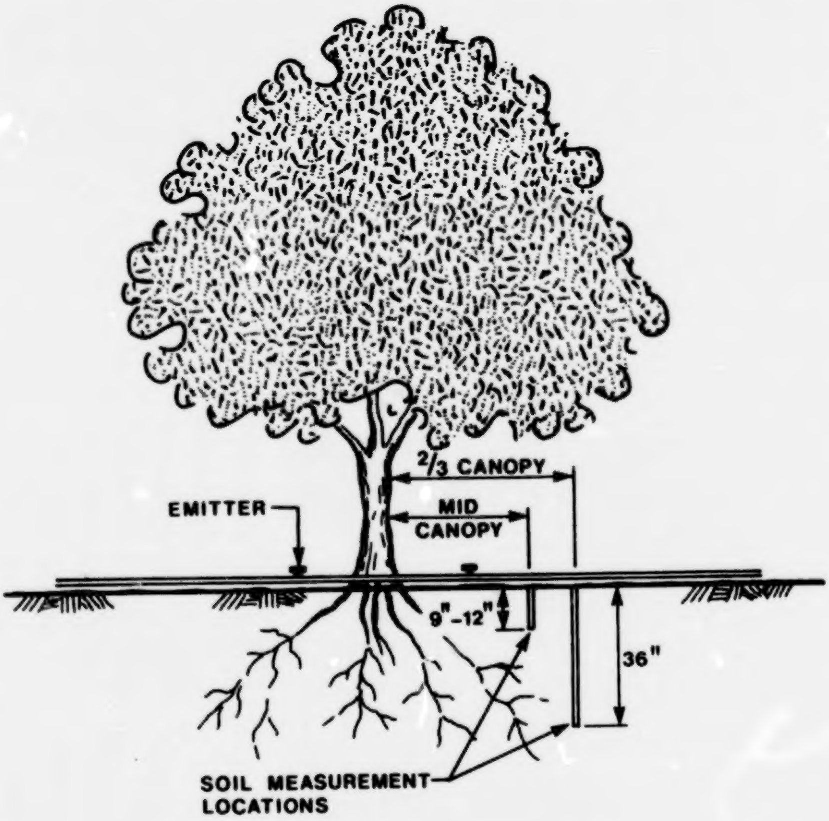


Figure 9.1 Soil Moisture Monitoring Location for Tree Fruits

**Electrical Resistance Blocks**

Electrical resistance blocks measure available soil moisture percentage. A calibration curve is required to determine the soil moisture percentage based on soil type and ohm resistance. Advantages of resistance blocks are:

- suitable to any depth
- stay in position and are easily read
- range of moisture determination is greater than tensiometers.

Resistance blocks have disadvantages which include:

- not suitable in gravelly, sandy or peat soils
- require good contact with the soil
- requires technical information for proper data interpretation
- may deteriorate in acidic soils.

Electrical resistance blocks should be installed at locations similar to those discussed under tensiometers. Monitoring the readings frequently will indicate if sufficient water is being applied.

## Tensiometers

Tensiometers give a direct reading of the soil moisture tension existing in the plant root zone. The instruments should be placed at strategic locations within the plant root zone, 18" from the emitter but within the wetted zone. Depending on the plants maximum rooting depth and soil type more than one tensiometer may be required per site. For example tree fruits should have a minimum of two tensiometers per site, one at a 12" depth and another one at a 30" depth. The number of stations required will depend on acreage, exposure, age of planting, and the number of soil types.

Tensiometers do require supervision and must be correctly installed in order to obtain reliable results. A grower will require two years of experience with these instruments before gaining confidence in the readings. For optimum irrigation results, tensiometers should read between the 20 to 30 centibar range.

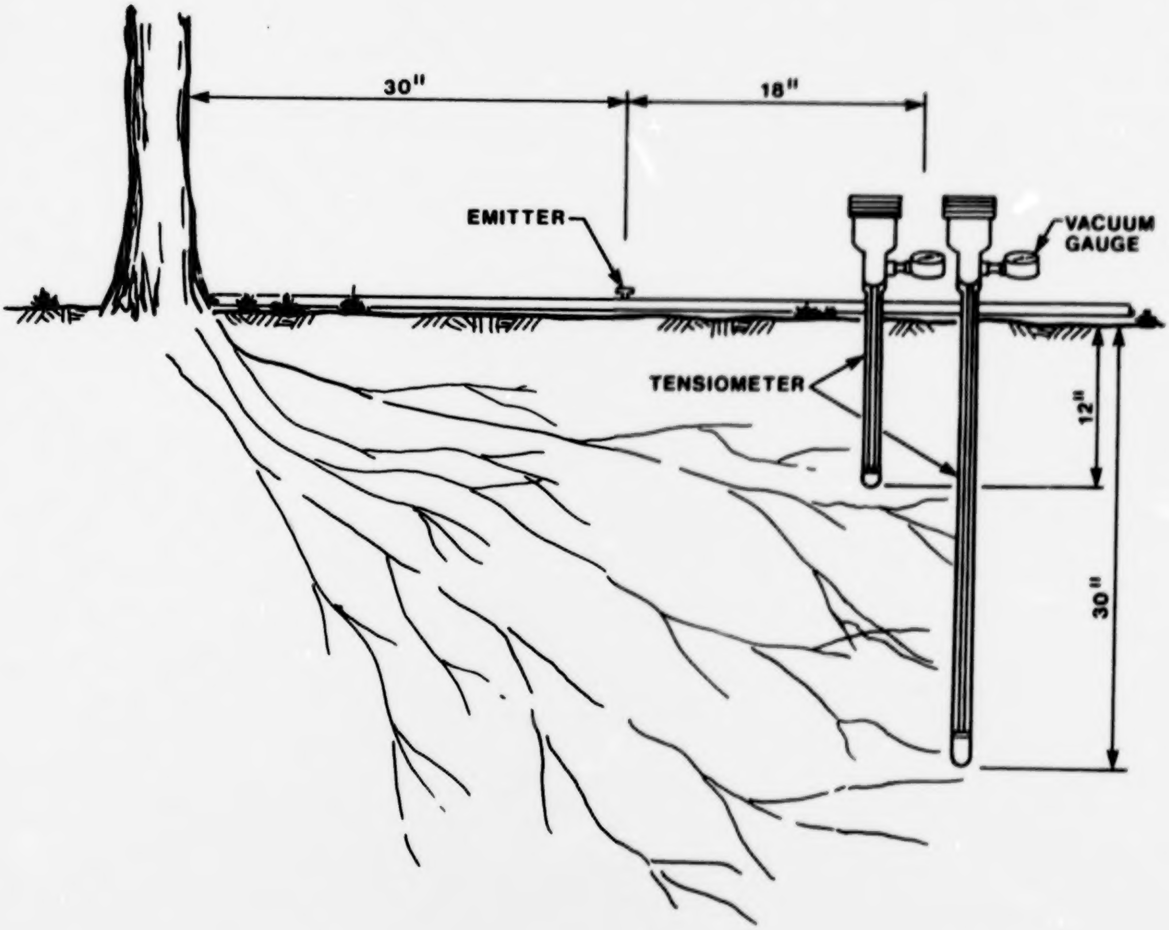


Figure 9.2 Tensiometer Installation

## 9.2 TRICKLE IRRIGATION SCHEDULING

A trickle irrigation scheduling system can be implemented with soil moisture data and evapotranspiration data. It is suggested that both data be collected to ensure the best possible scheduling.

### Obtaining Evapotranspiration Data

Wind, temperature, humidity and radiation affect the evapotranspiration from a crop. Evaporation from a Class A pan or Bellani Plate is affected by the same parameters. However, a pan or plate factor must be applied to the evaporation reading to correct for soil type, cover crop, age of planting and exposure. The appropriate factor can be established in time by using tensiometers. Figure 9.3 indicates pan dimensions required to obtain the best results. A Class A pan is very expensive. A washtub or other pans of similar dimensions can be substituted but different pan factors will result. The reliability of readings may also pose a problem. Considerable time will be required to establish a reliable pan factor. Also, evapotranspiration data will vary from day to day, requiring an adjustment in application times. Practically, the application times should be adjusted every four or five days, rather than attempting to adjust them daily.

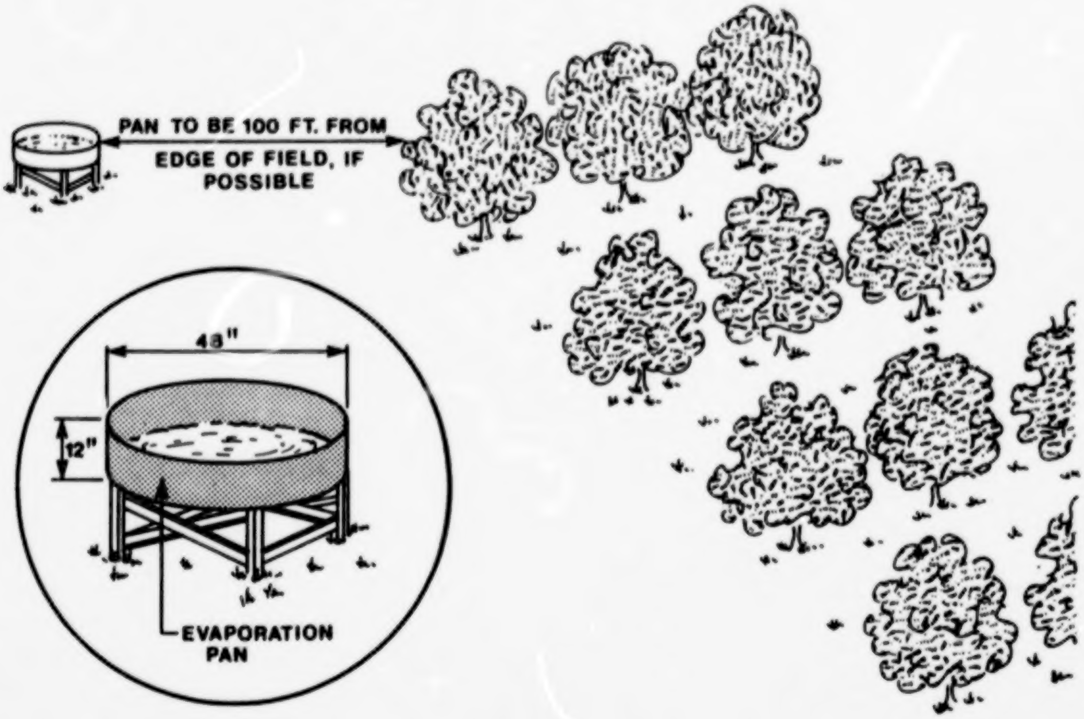


Figure 9.3 Evaporation Pan Dimensions

An example trickle irrigation scheduling method using evapotranspiration data and tensiometer readings is outlined below.

Example 1 on page 2-7 will be used.

- apples on a 10ft x 20ft planting in loam soil in the Kelowna area
- plant water requirement is 20.0 G/P/D during peak time of year
- trickle system design requirement is 24.7 G/P/D.

Assume the following:

Pan evaporation is 0.15 in/day.
Use a pan factor of 0.8. Actual ET is 0.15 x 0.8 = 0.12 in/day.

G/P/D = 0.623 x ET x S x A x K

G/P/D = 0.623 x ET x 0.75 x 200 x 0.90

Therefore based on a pan reading of 0.15 in/day (adjusted to 0.12 in/day)
the required G/P/D = 0.623 x 0.12 x 0.75 x 200 x 0.90
= 12 gallons per plant per day

The trickle system should be operated long enough to apply 12 G/P/D for the mature trees. The pan readings and corresponding operating times would be continued using the 0.8 pan factor. Monitoring the tensiometers will indicate whether enough or too little moisture is applied. The tensiometers should be maintained in the 20 to 30 centibar range. The pan factor can be adjusted up or down depending on whether tensiometer readings drop or climb.

A pan factor will be established once the tensiometer readings have stabilized when irrigating according to pan ET data.

Evapotranspiration data may also be obtained from Environment Canada, Agriculture Canada, or irrigation districts cooperating in scheduling programs.

## Determining Trickle Irrigation Intervals

The trickle irrigation concept is to apply enough water to replenish the crop water requirement on a daily basis. However, soil type, soil drainage conditions and climate should be taken into account before deciding on a trickle irrigation schedule.

The least expensive trickle system would be designed with continuous water application. System flow rates would be reduced thereby reducing pipe sizes and minimizing control and zone valves. Continuous operation, however, leads to several problems, including excessive algae buildup, overwatering which induces leaching or runoff and, waterlogging, which can be detrimental to several crops. It is recommended that intermittent operation is used for a trickle system. Each zone should not be operated or more than 12 hours per day. This criteria should be used in determing the number of emitters per plant. See Chapter 5 for additional information on selecting the number of emitters per plant.

Short irrigation intervals are required in regions where evapotranspiration rates are high, the available water storage capacity of the soil is low, water quality is poor (saline) or if plants are shallow rooted. Longer irrigation intervals can be used if evapotranspiration is low, the available water storage capacity of the soil is high, water quality is good, or plants are deep rooted.

Trickle irrigation systems in B.C. are designed to supply sufficient moisture during the peak of the season. The duration of application must be adjusted to accomodate non-peak conditions. The irrigation interval can be selected in conjunction with the duration of application. Table 9.1 provides suggested irrigation intervals based on climate (as expressed by ET), soils and rooting depths. The values shown should be used as a guide, taking climatic trends into account. See Chaper 5 for further information on duration of application.

Table 9.1 Maximum Irrigation Intervals for Trickle Irrigation Systems

| ET | Rooting Depth (ft) | Soil<br>Coarse Sand | Sandy Loam | Loam | Clay |
|---|---|---|---|---|---|
| 0.30 | 2 ft | 1 day | 1 day | 1 day | 1 day |
| in/day | 4 ft | 1 | 1 | 1 | 2 |
| 0.26 | 2 ft | 1 | 1 | 1 | 2 |
| in/day | 4 ft | 1 | 1 | 1 | 2 |
| 0.22 | 2 ft | 1 | 1 | 1 | 2 |
| in/day | 4 ft | 1 | 1 | 2 | 3 |
| 0.18 | 2 ft | 1 | 1 | 2 | 3 |
| in/day | 4 ft | 1 | 1 | 2 | 4 |
| 0.14 | 2 ft | 1 | 1 | 2 | 4 |
| in/day | 4 ft | 1 | 2 | 3 | 6 |

In very coarse soils it is important that the trickle systems operate during the time period when the plant is using the most water, as soil water storage is minimal. A trickle system should be operated frequently for coarse soils.

A very heavy soil may require longer off periods to prevent waterlogging of the soil and associated plant deseases such as crown rot.

The duration of application, as stated above, should not exceed 12 hours. The irrigation interval selected must therefore allow the trickle system to apply the crop's water requirement for the irrigation interval within a 12 hour time duration.

## Example

Determining if there are sufficient emitters per plant.

Example 1 page 2-7 - A tree fruit crop requires a total of 20.2 G/P/D/. The trickle system design requirement is 24.7 G/P/D/.

Example 1a - page 2-10 - If a 1 gph emitter is spaced every 4 ft along the tree row, each zone must operate for 9.9 hrs/day to apply enough water. The maximum irrigation interval would then be $\frac{12 \text{ hrs}}{9.9 \text{ hrs/day}} = 1.2$ days.

If a 2 day irrigation interval was desired the system must be capable of applying the total of 2 days x 24.7 G/P/D/ = 49.4 gallons in 12 hours. This would work out to four 1 gph emitters installed per tree.

Twice the emitters would therefore be required to accomodate the 2 day irrigation interval in this particular example.

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  16 mm I.D. P.E. A-5
  20 mm P.E. A-6
  26 mm P.E. A-7

Figures From Hardie Irrigation Company

Appendix B Bi-Wall Pressure Loss and Flow Curves
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From T-Systems Corporation

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Appendix E Trickle Irrigation Design Information Sheet E-1

Appendix F Metric Conversion Table (Imperial to Metric) F-1

## APPENDIX A

**Figure A.1** SDR CURVE FOR 10mm POLYETHYLENE HOSE

(0.390 in. I.D.)

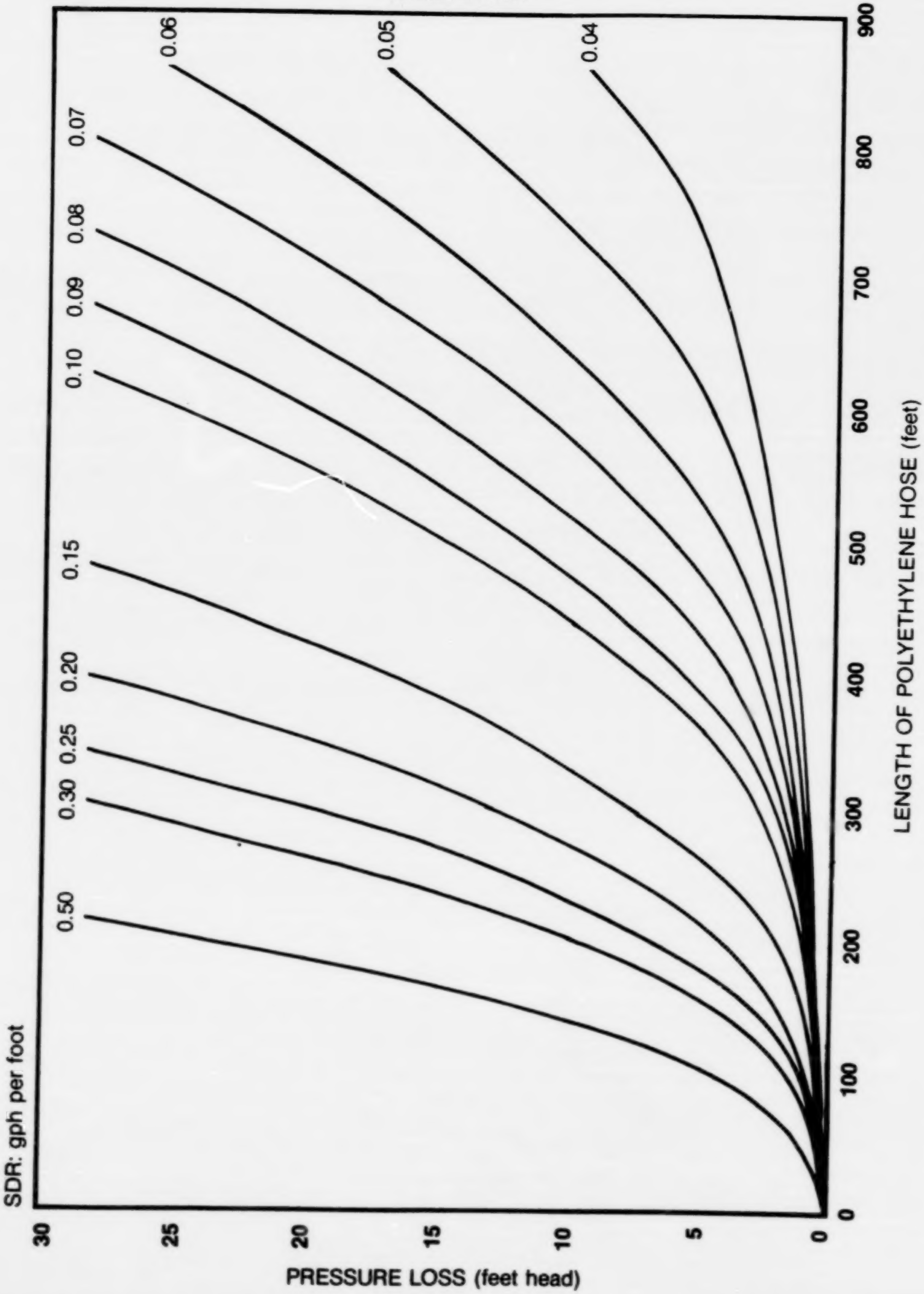


**Figure A.2** SDR CURVE FOR 13mm POLYETHYLENE HOSE

(0.510 in. I.D.)

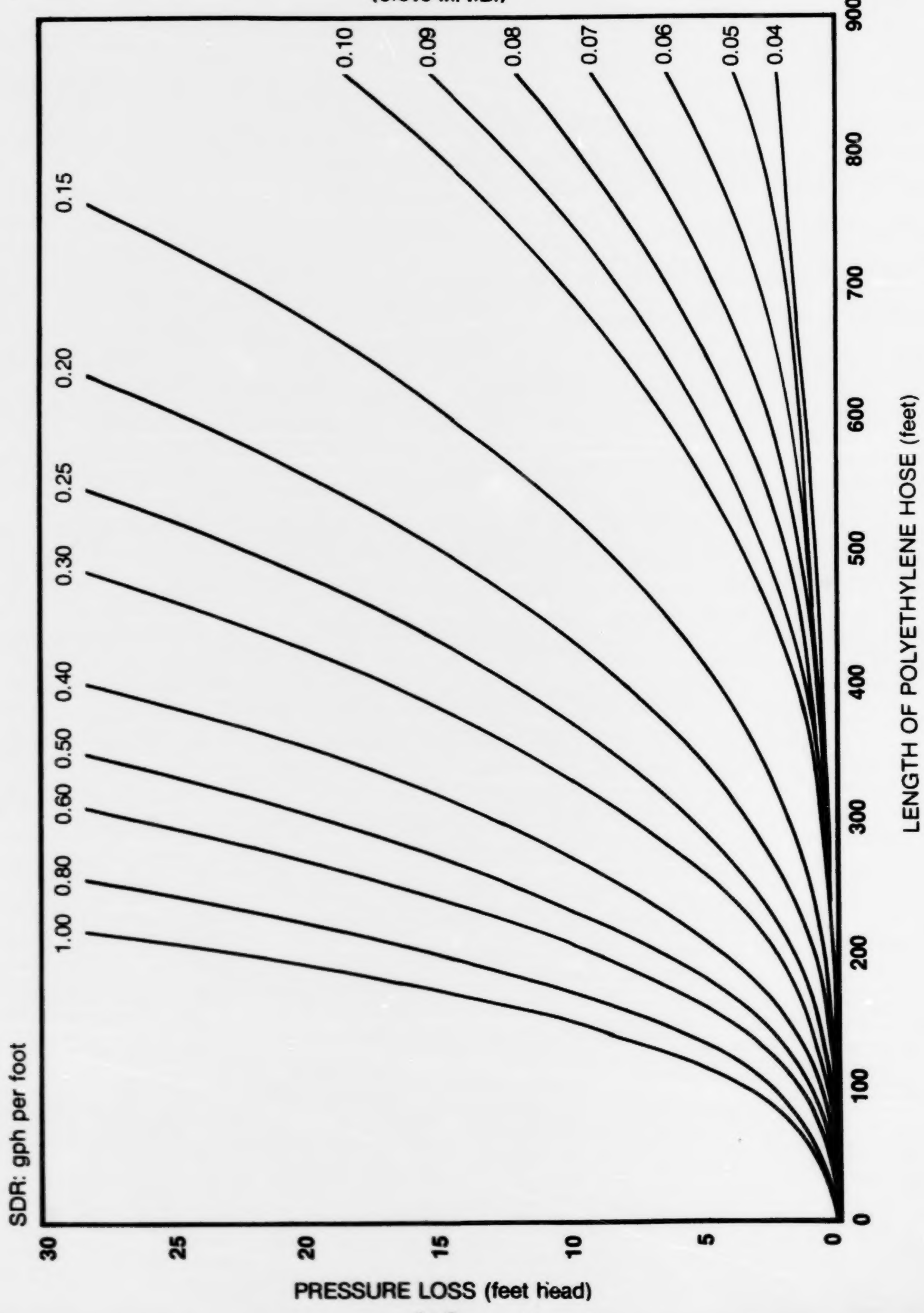


Figure A.3 SDR CURVE FOR 15mm POLYETHYLENE HOSE

(0.580 in. I.D.)

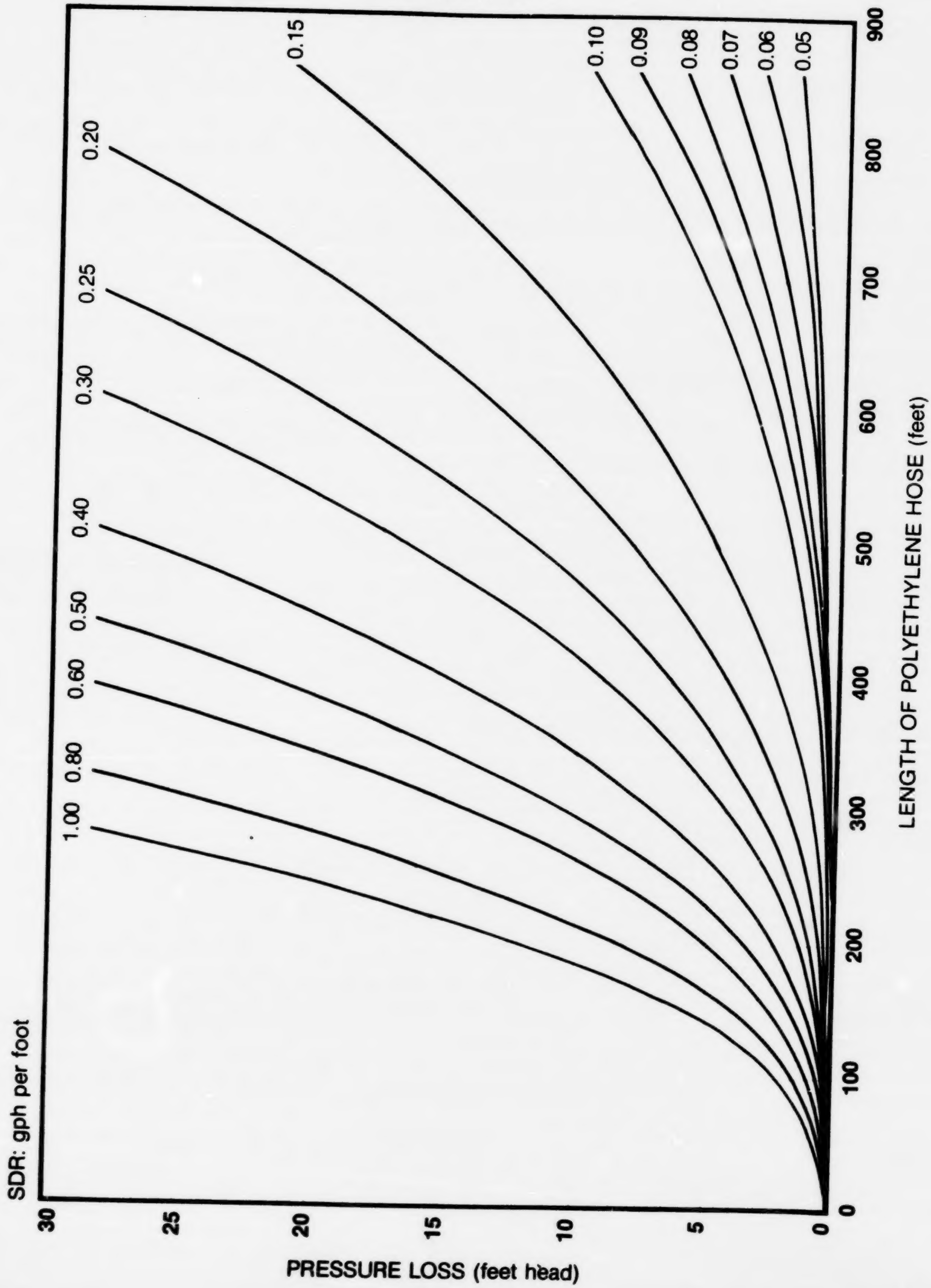


Figure A.4 **SDR CURVE FOR 16mm O.D. POLYETHYLENE HOSE**

**(0.600 in. I.D.)**

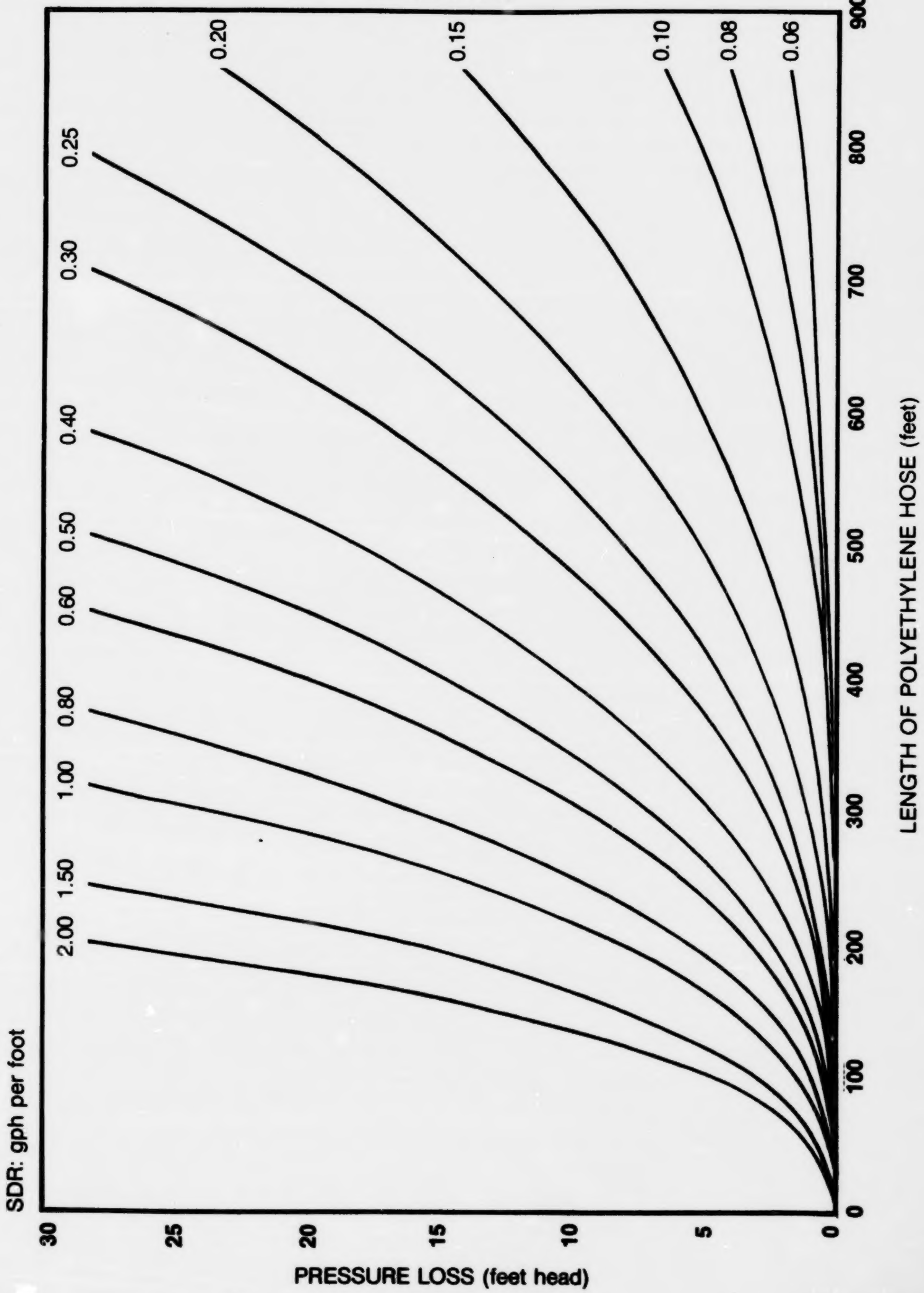


**Figure A.5** SDR CURVE FOR 16 mm I.D. POLYETHYLENE HOSE

(0.630 in. I.D.)

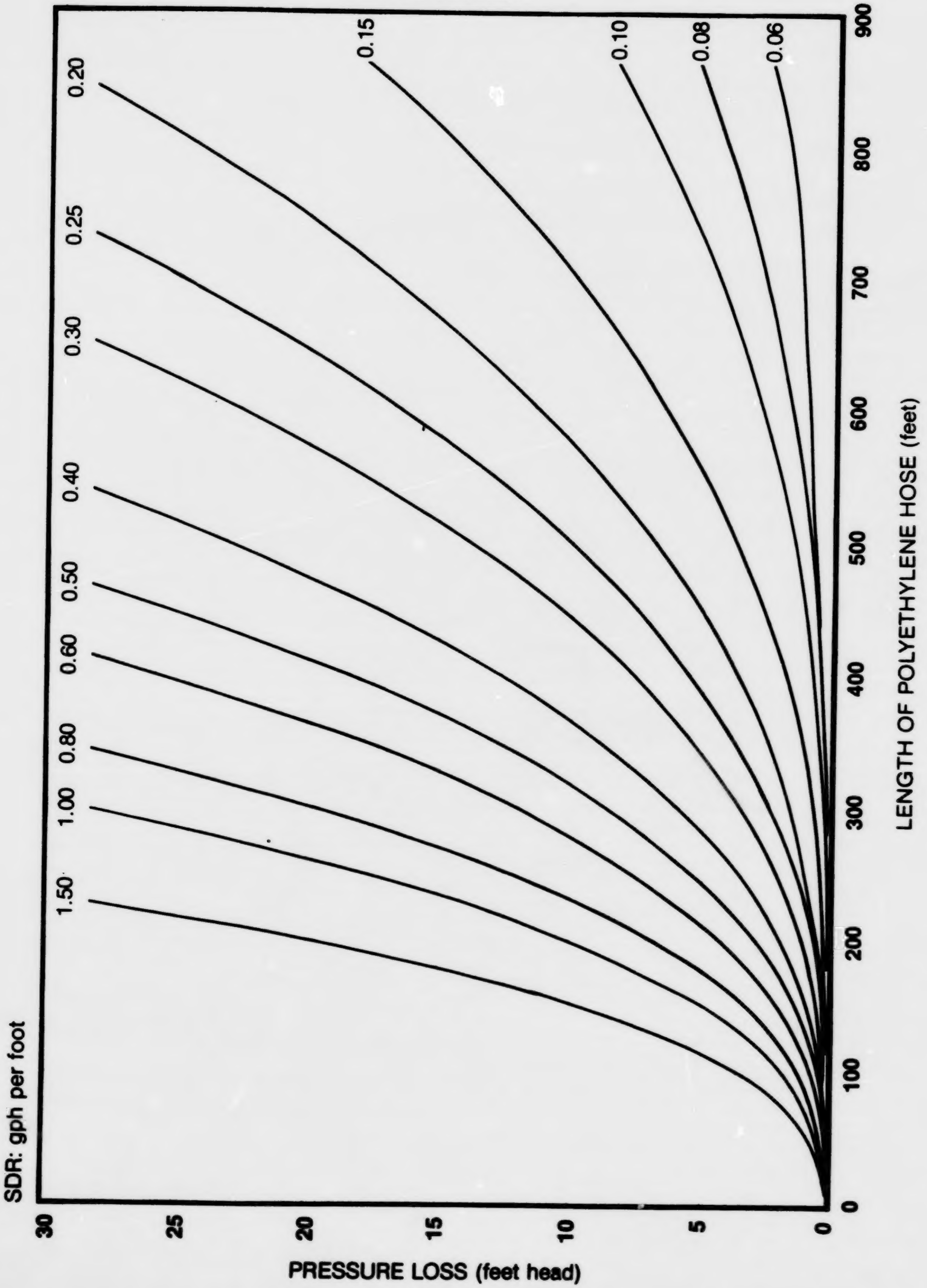


**Figure A.6** SDR CURVE FOR 20mm POLYETHYLENE HOSE

(0.800 in. I.D.)

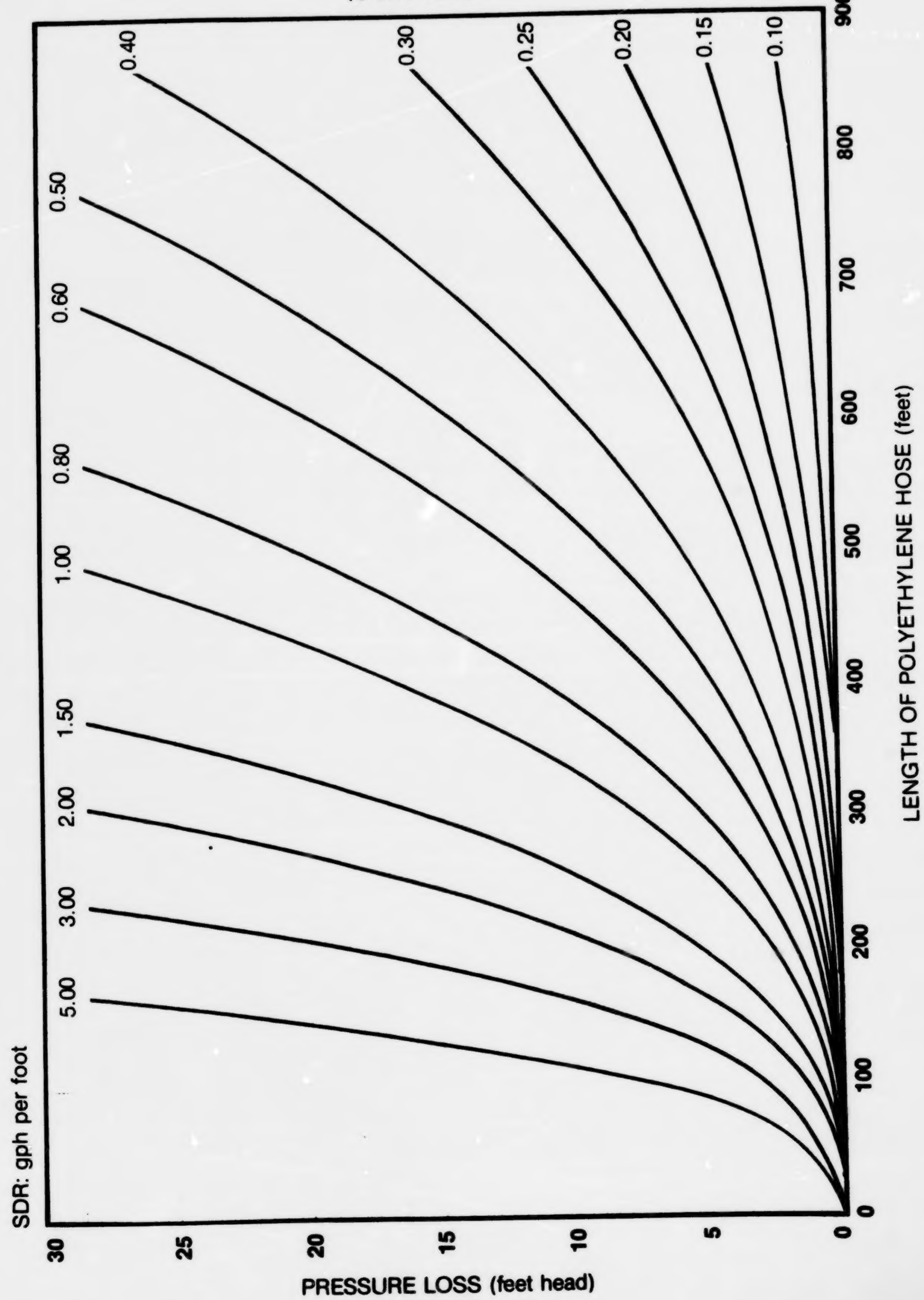
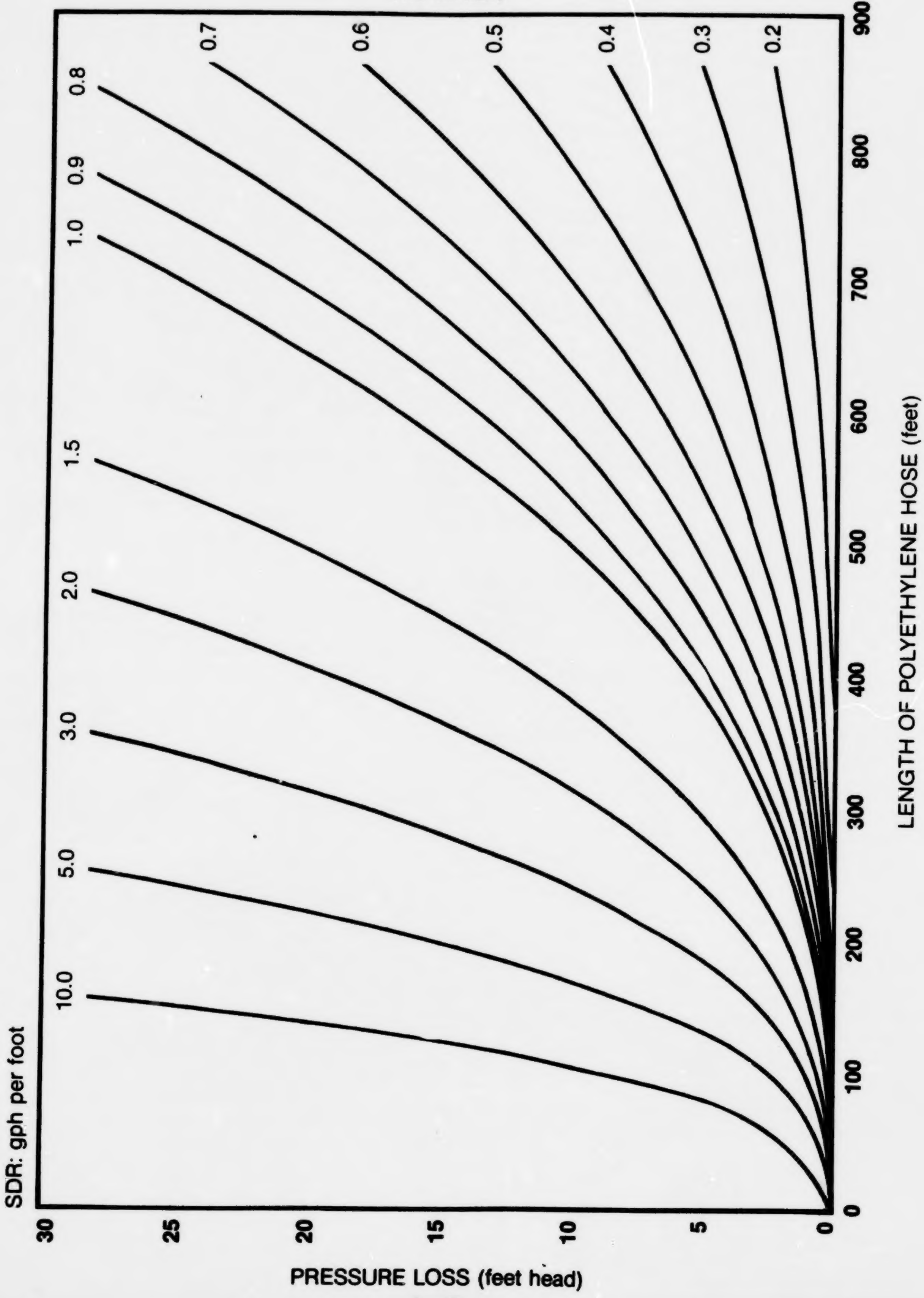


**Figure A.7** SDR CURVE FOR 26 mm POLYETHYLENE HOSE

(1.0 in. I.D.)



# APPENDIX B

Figure B.1 BI-WALL 6" x 36" PRESSURE LOSS CURVE

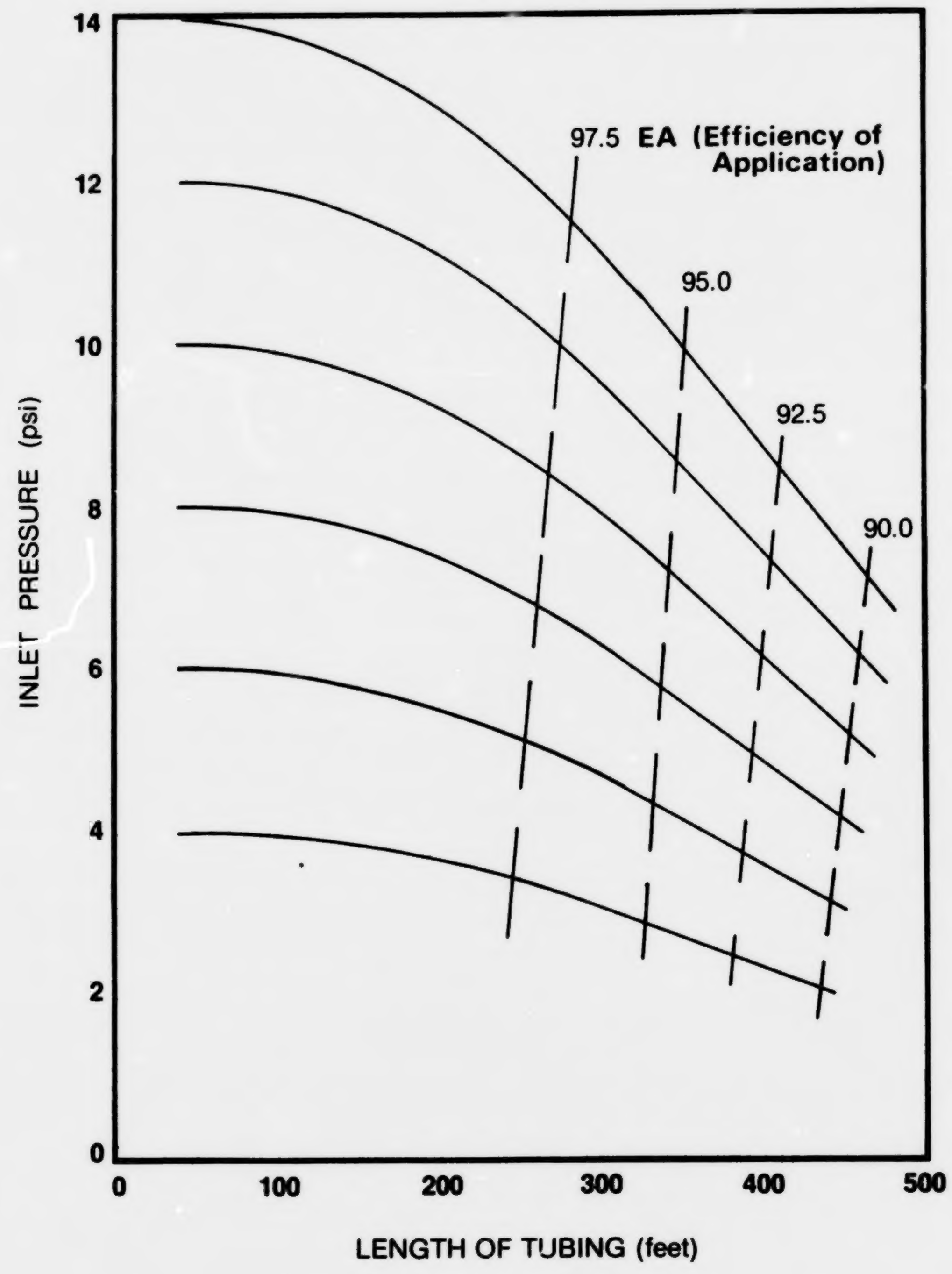


Figure B.2

## BI - WALL 6" x 36" FLOW CURVE

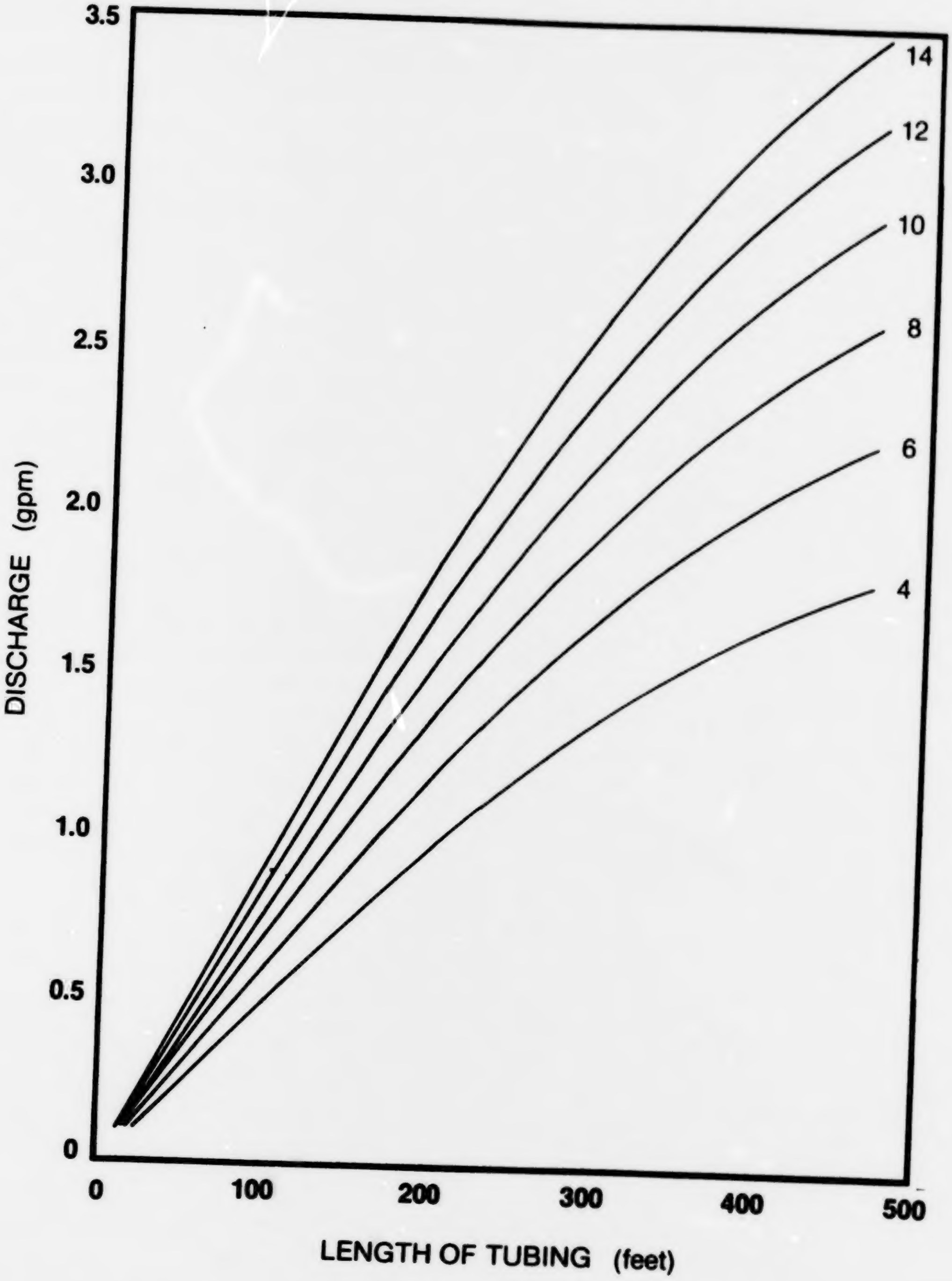


Figure B.3 BI-WALL 12" x 60" PRESSURE LOSS CURVE

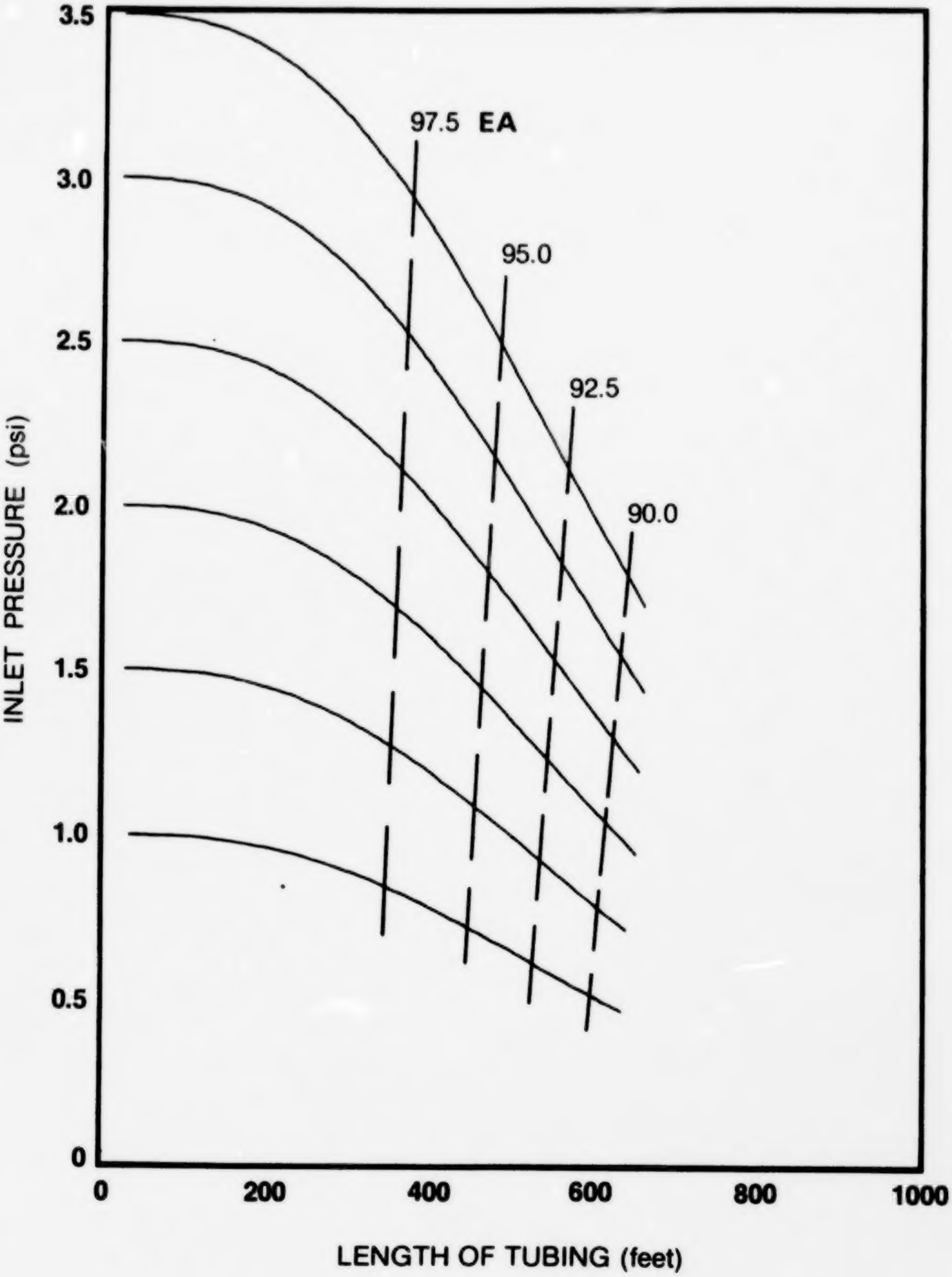


Figure B.4 BI-WALL 12" x 60" FLOW CURVE

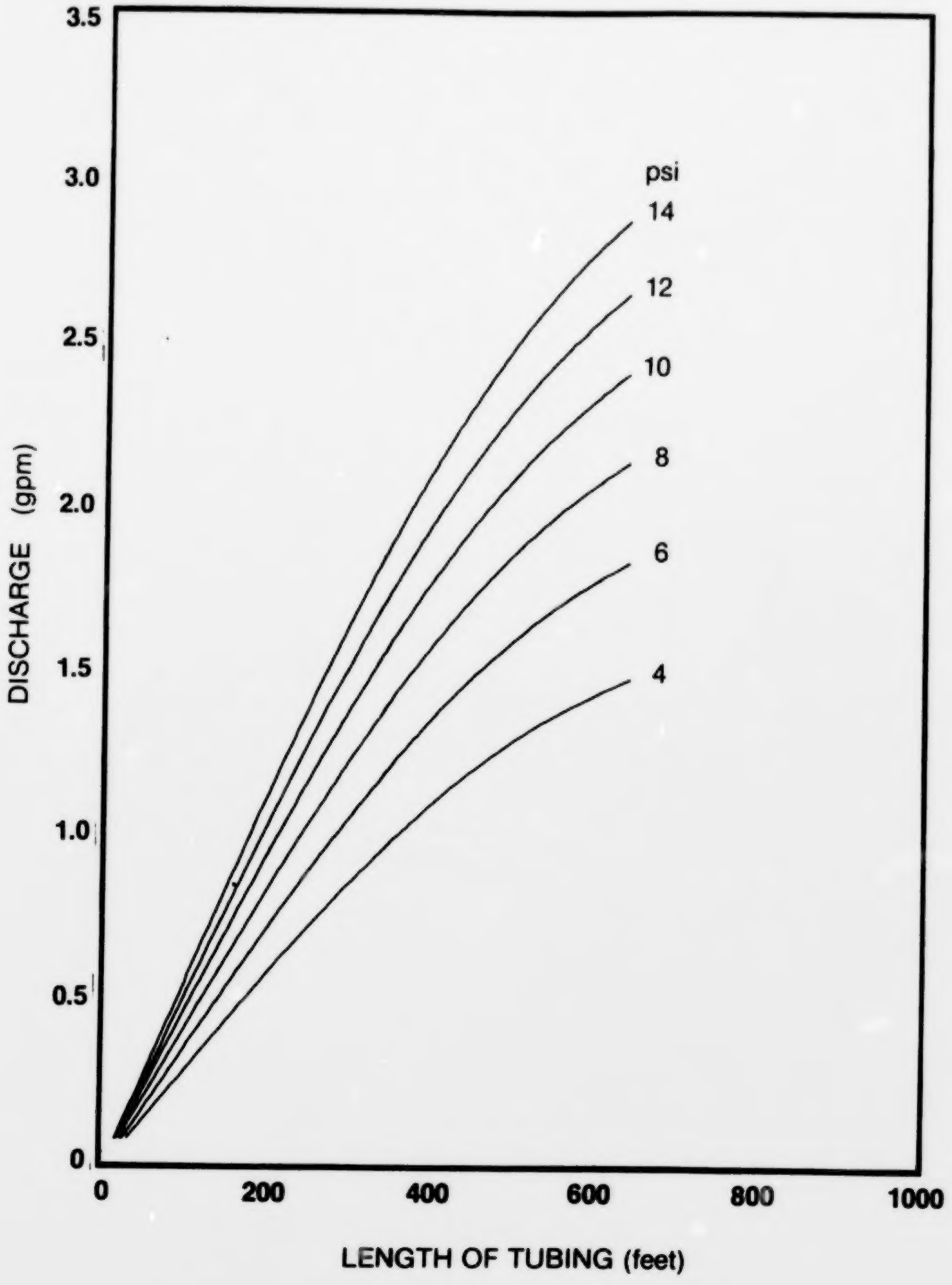


**Figure B.5** Bi-Wall 12"x72" PRESSURE LOSS CURVE

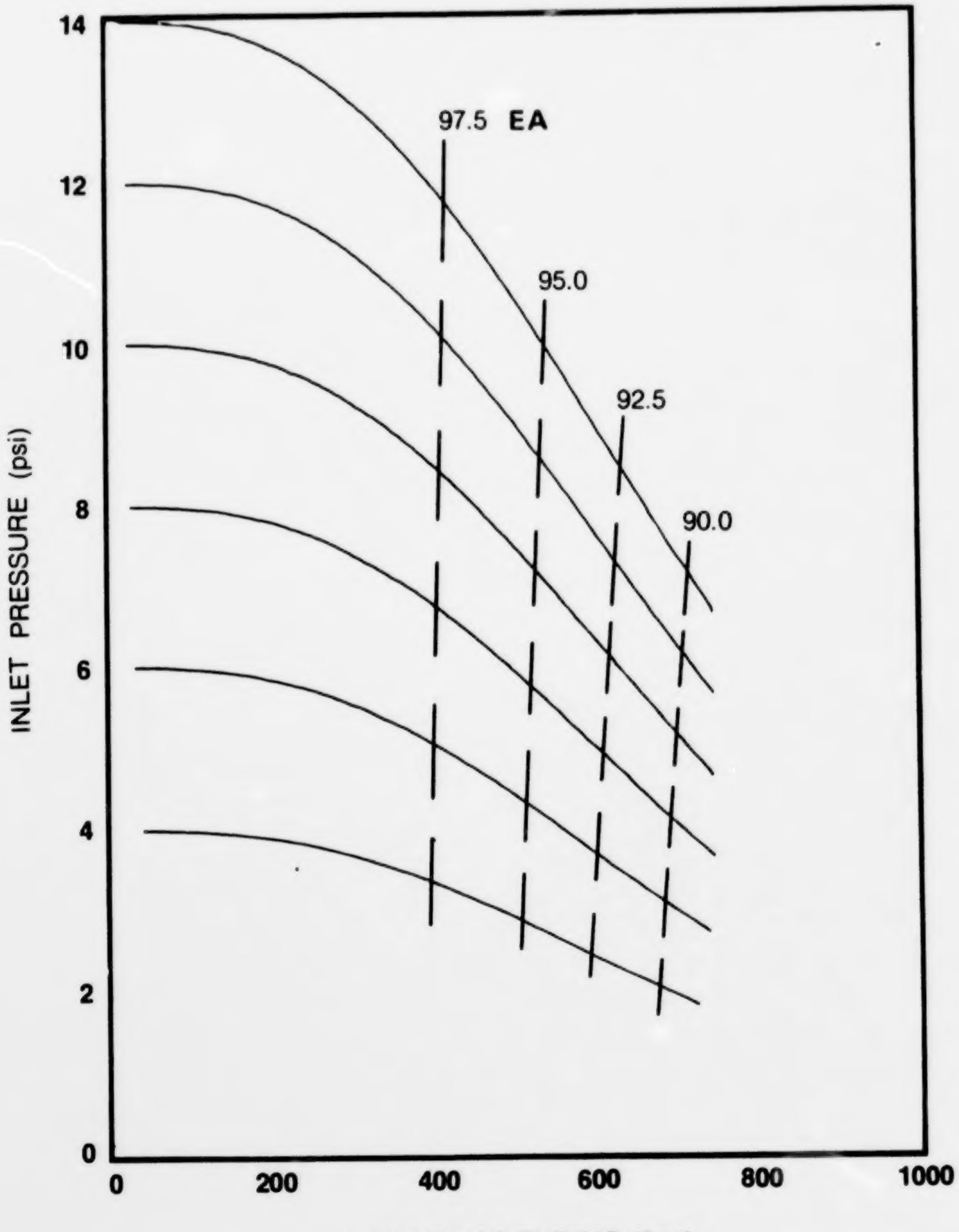


**Figure B.6** Bi-Wall 12" x 72" FLOW CURVE

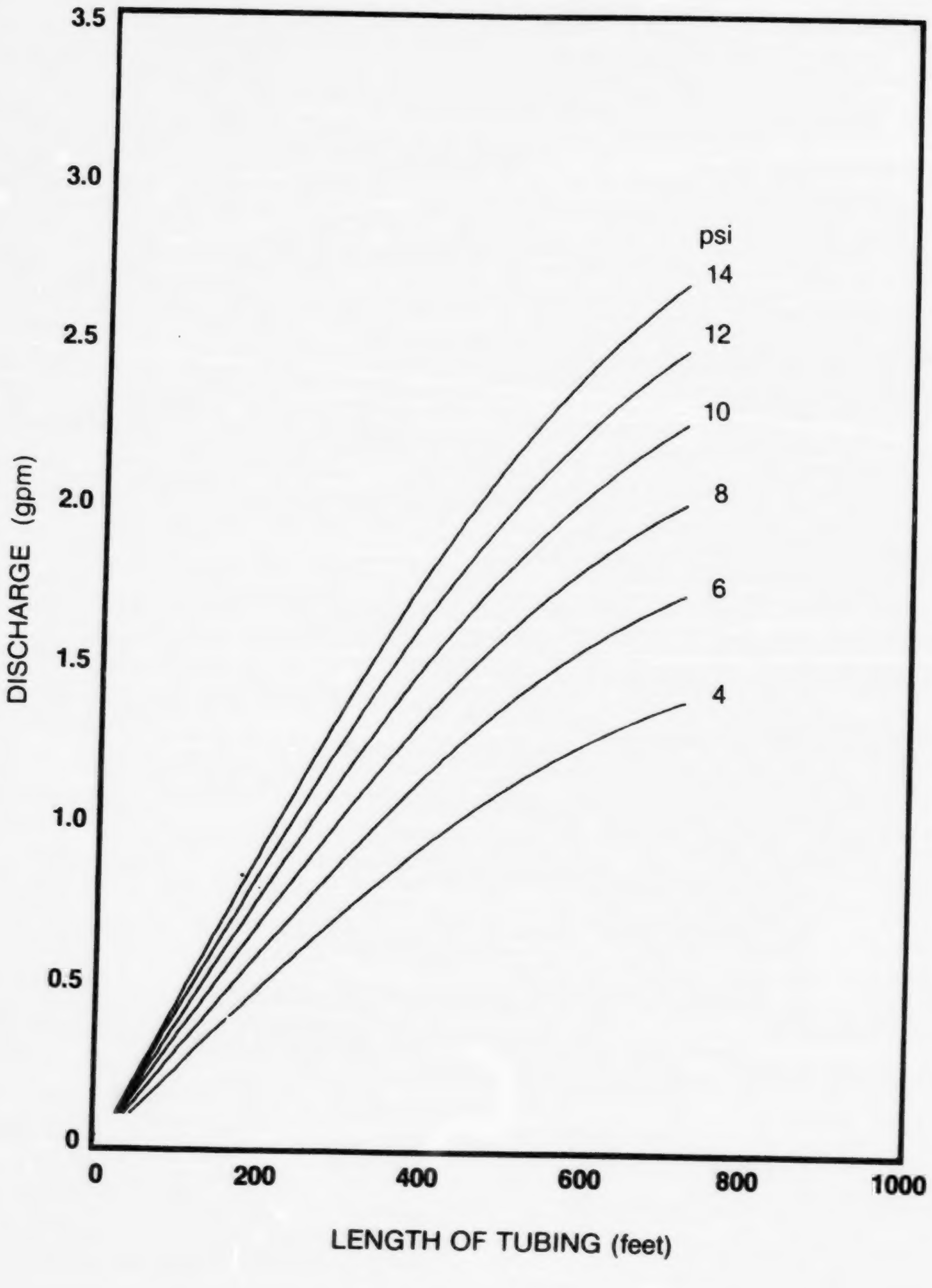
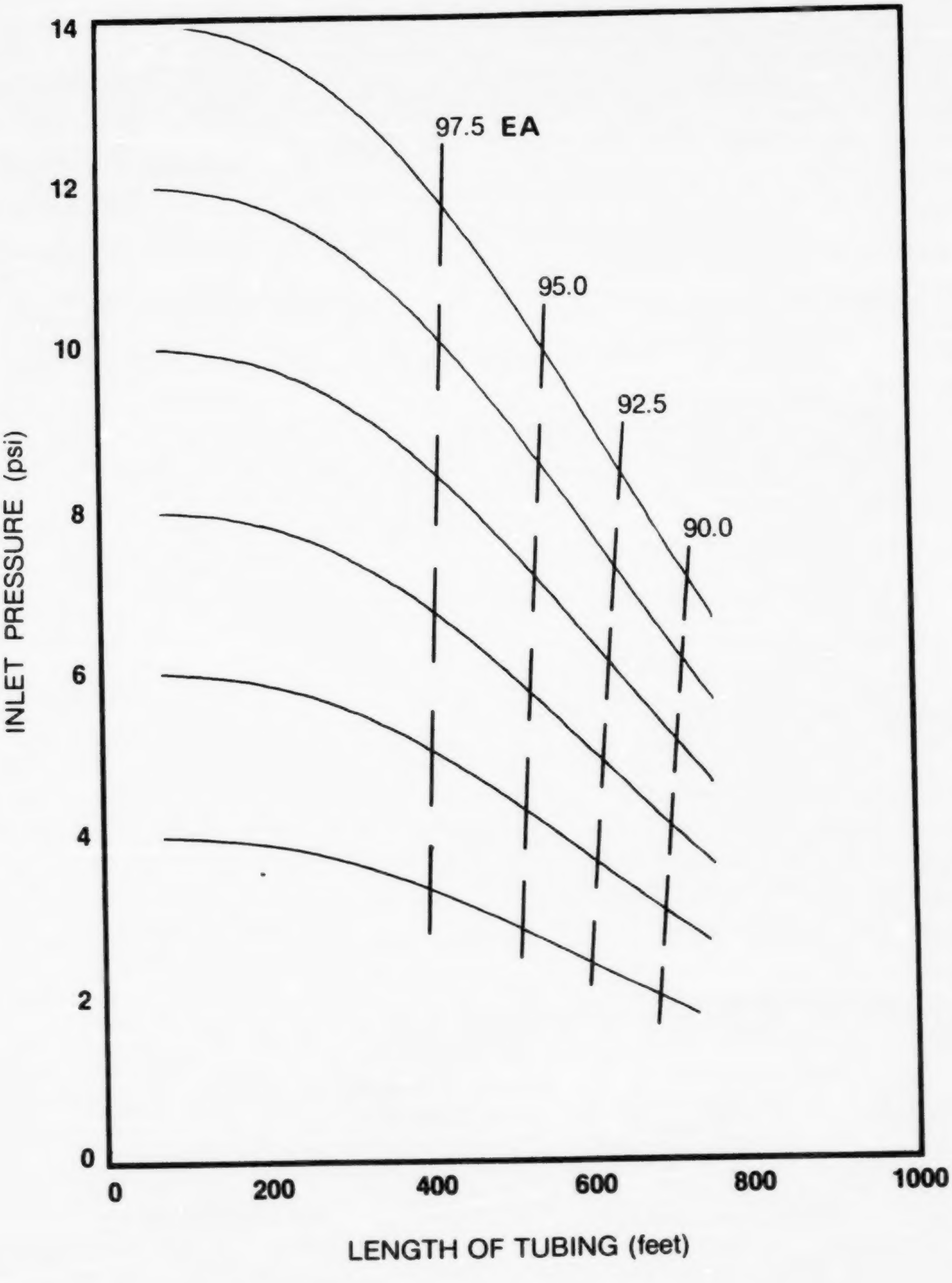


**Figure B.7** Bi-Wall 18" x 72" PRESSURE LOSS CURVE



. **Figure B.8** **Bi-Wall 18" x 72" FLOW CURVE**

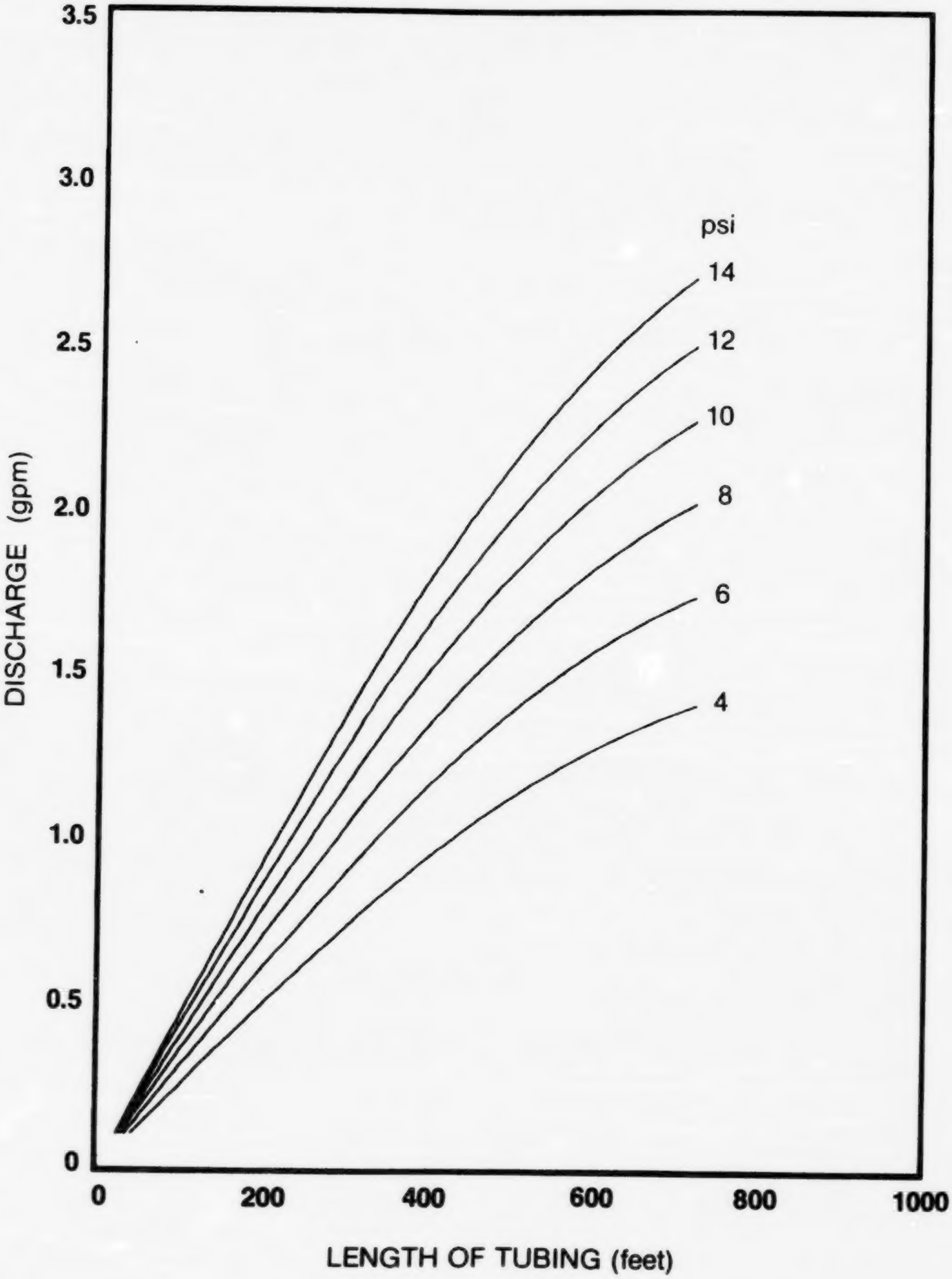


Figure B.9 Bi-Wall 18" x 90" PRESSURE LOSS CURVE

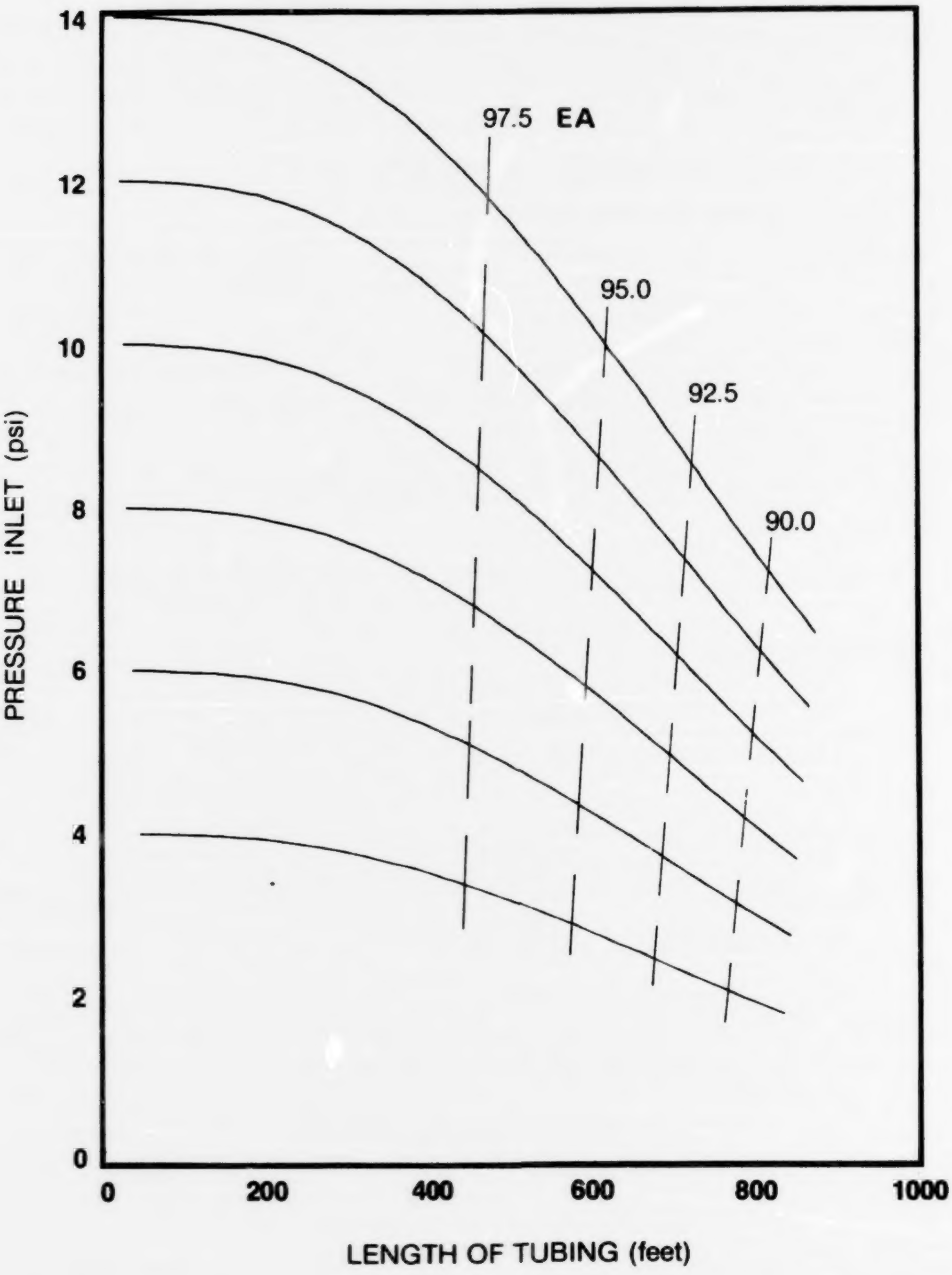


**Figure B.10** Bi-Wall 18" x 90" FLOW CURVE

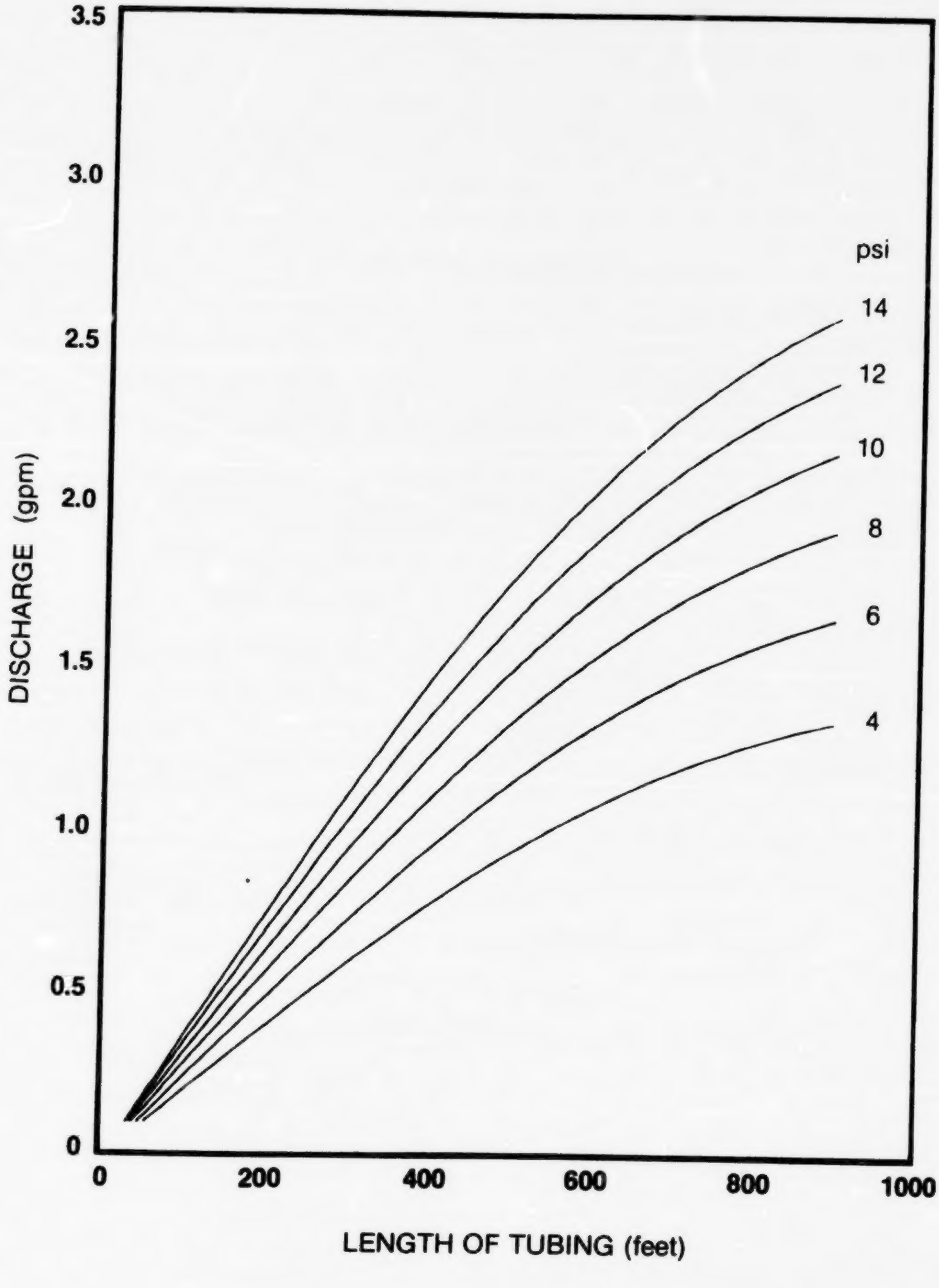


Figure B.11 Bi-Wall 24" x 96" PRESSURE LOSS CURVE

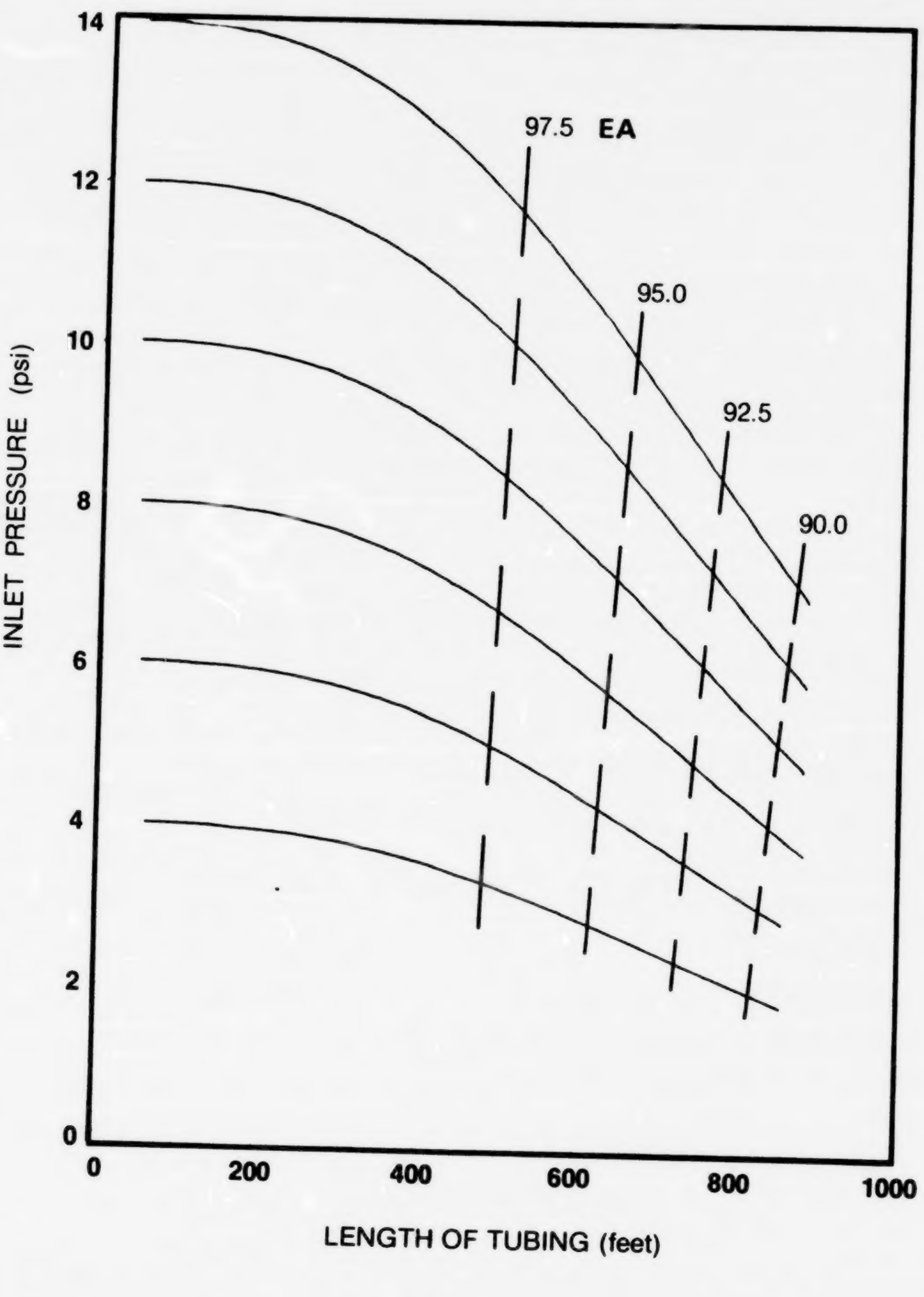


Figure B.12

## Bi - Wall 24" x 96" FLOW CURVE

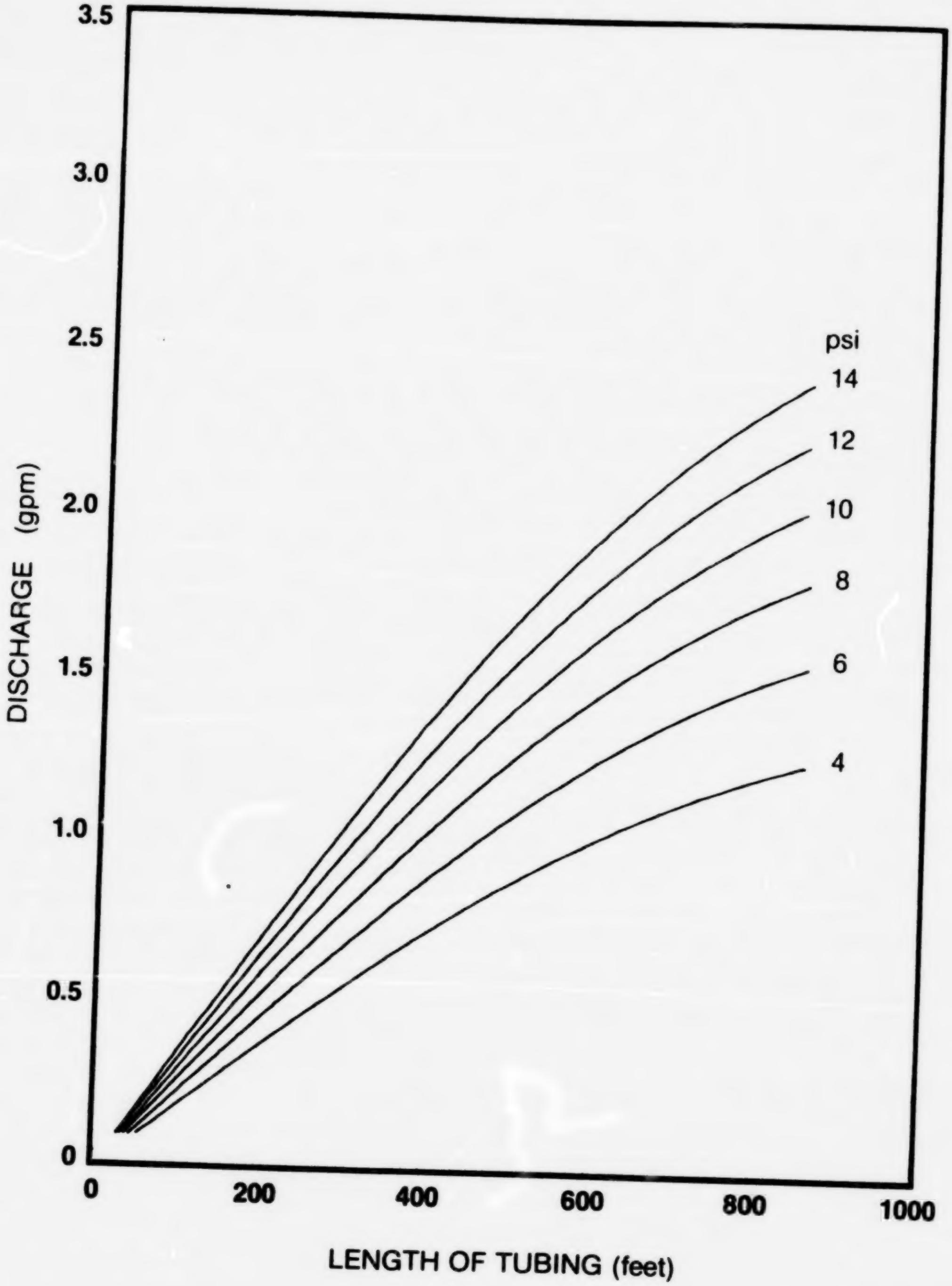


**Figure B.13** Bi-Wall 36" x 144" PRESSURE LOSS CURVE

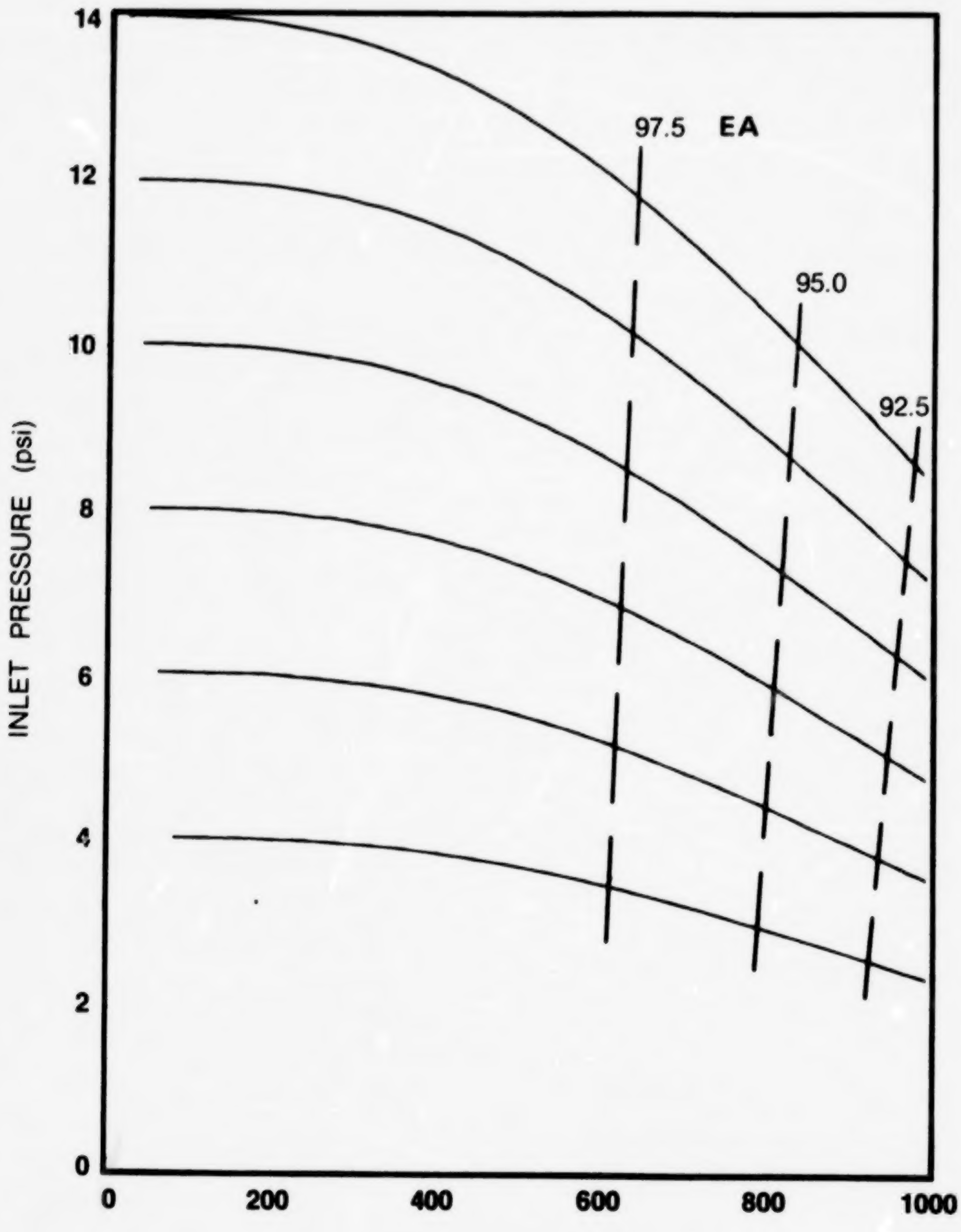


**Figure B.14** Bi-Wall 36" x 144" FLOW CURVE

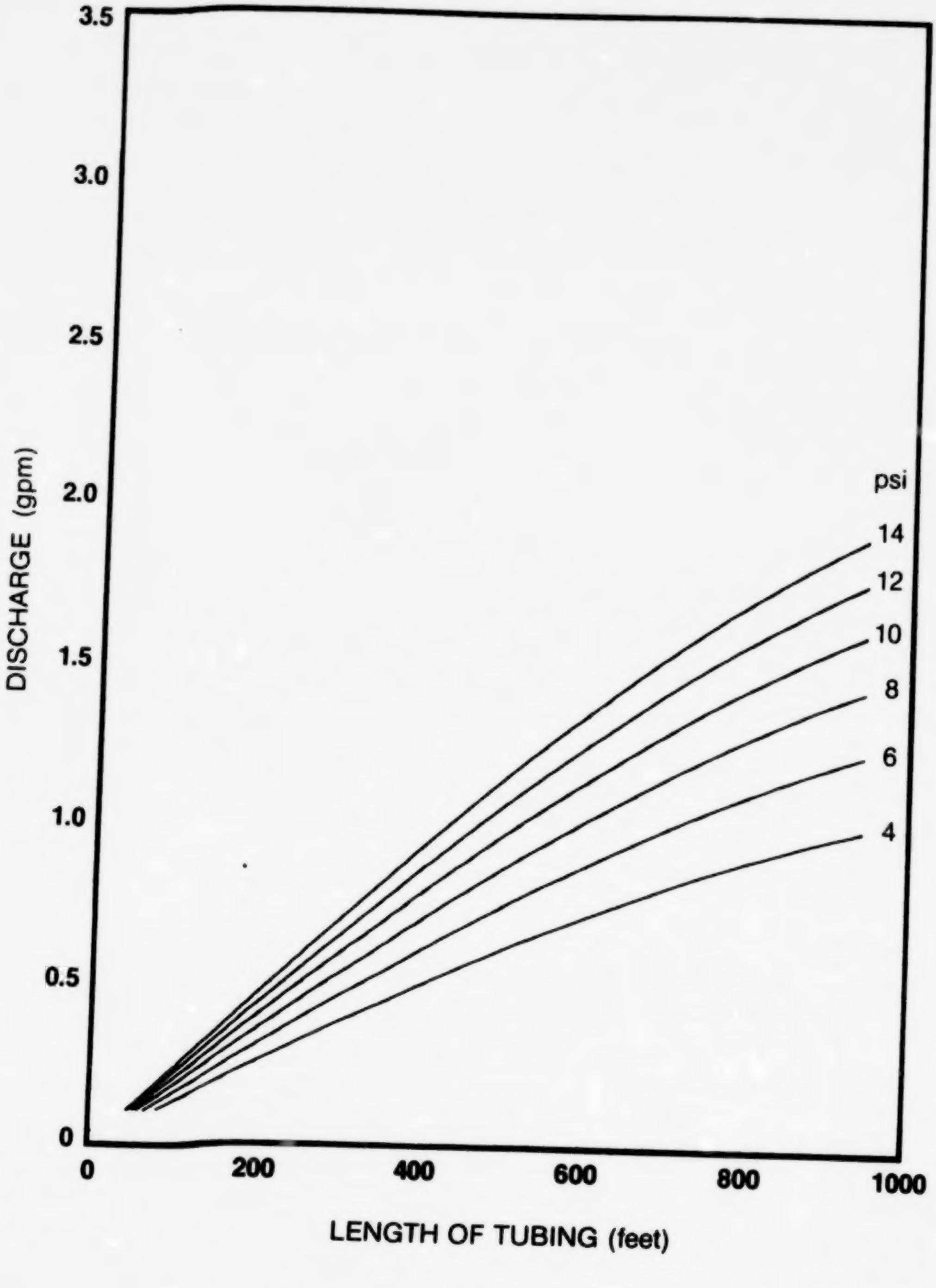


Figure B.15 Tree-Line 36" x 144" PRESSURE LOSS CURVE

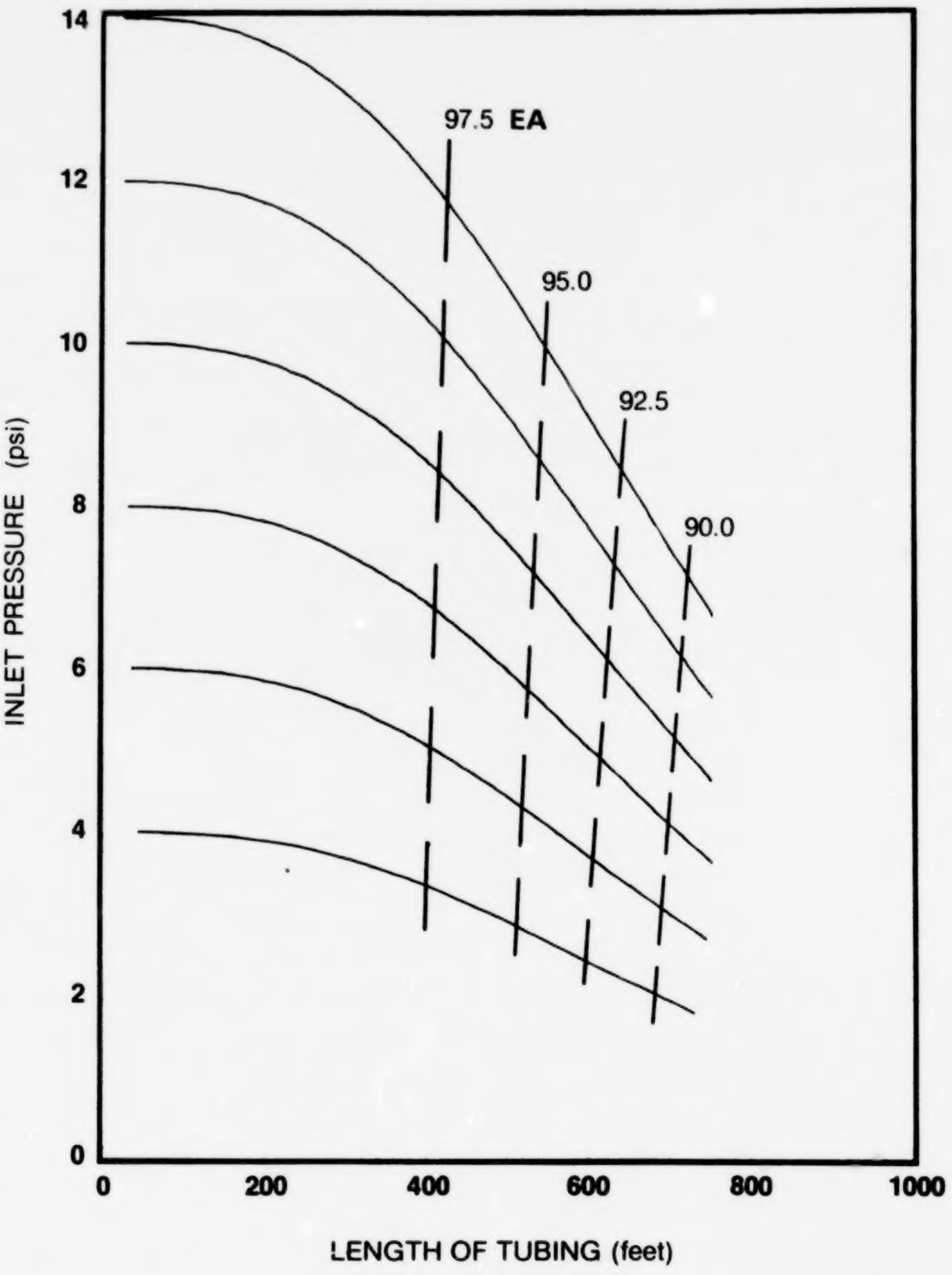


**Figure B.16** Tree-Line 36" x 144" FLOW CURVE

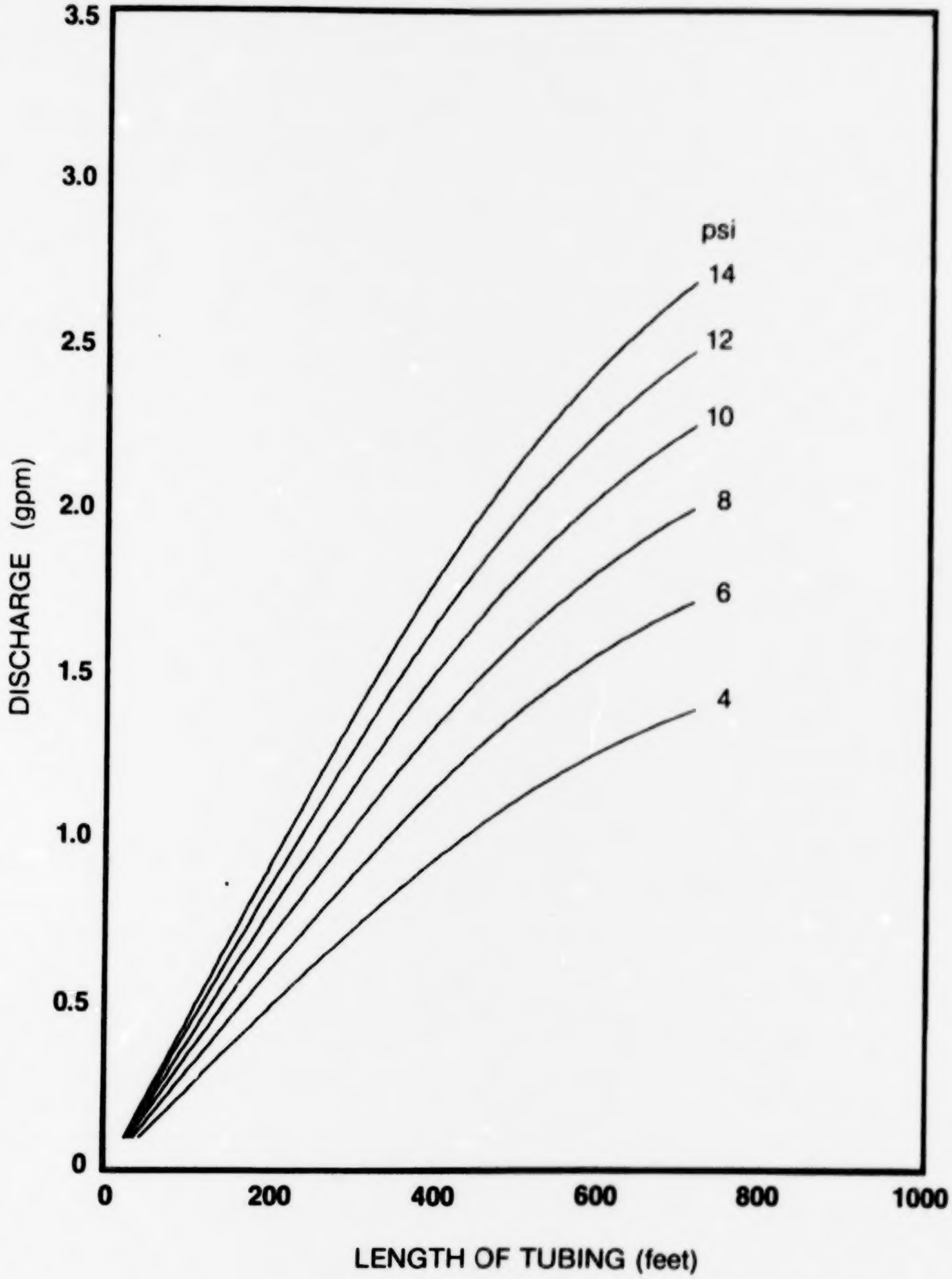


Table B.1 T-Tape Flow Rates

| Flow Rates at 8 psi | | | Lengths of Run (ft @ 8 psi) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Percent Slope | | | | | | |
| | | | Uphill | | | | Downhill | | |
| Outlet Spacing | Flow Rate per 100 ft of T-Tape (gph) | Uni-formity of flow | 3% | 2% | 1% | 0 | 1% | 2% | 3% |
| High Flow | | | | | | | | | |
| 8 in | 40 | ±10% | 150 | 250 | 300 | 350 | 450 | 500 | 450 |
| | | ±15% | 250 | 300 | 350 | 400 | 500 | 600 | 550 |
| | | ±20% | 300 | 350 | 400 | 450 | 500 | 600 | 600 |
| 12 in | 24 | ±10% | 200 | 250 | 350 | 500 | 600 | 700 | 450 |
| | | ±15% | 300 | 400 | 500 | 550 | 700 | 800 | 750 |
| | | ±20% | 350 | 450 | 550 | 600 | 750 | 825 | 850 |
| 16 in | 20 | ±10% | 150 | 300 | 400 | 550 | 750 | 800 | 400 |
| | | ±15% | 300 | 400 | 500 | 650 | 800 | 950 | 850 |
| | | ±20% | 350 | 450 | 600 | 700 | 850 | 950 | 950 |
| Low Flow | | | | | | | | | |
| 8 in | 20 | ±10% | 150 | 300 | 400 | 550 | 750 | 800 | 400 |
| | | ±15% | 300 | 400 | 500 | 650 | 800 | 950 | 850 |
| | | ±20% | 350 | 450 | 600 | 700 | 800 | 950 | 950 |
| 12 in | 12 | ±10% | 200 | 350 | 500 | 800 | 1000 | 600 | 350 |
| | | ±15% | 350 | 450 | 700 | 900 | 1100 | 1200 | 750 |
| | | ±20% | 400 | 550 | 750 | 1000 | 1150 | 1300 | 1250 |
| 16 in | 10 | ±10% | 200 | 300 | 450 | 850 | 1150 | 500 | 350 |
| | | ±15% | 350 | 450 | 750 | 950 | 1250 | 1250 | 700 |
| | | ±20% | 400 | 600 | 800 | 1000 | 1350 | 1450 | 1350 |

From T-Systems Corporation

# APPENDIX C

Table C.1 **Friction Loss - Polyethylene (PE) SDR-Pressure Rated Pipe**

Pressure Loss from Friction in psi per 100 ft of Pipe

| Flow |  |  |  | Nominal Size |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| (gpm) | 1/2" | 3/4" | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" |
| 1 | 0.49 | 0.12 | 0.04 | 0.01 |  |  |  |  |
| 2 | 1.76 | 0.45 | 0.14 | 0.04 | 0.02 |  |  |  |
| 3 | 3.73 | 0.95 | 0.29 | 0.08 | 0.04 | 0.01 |  |  |
| 4 | 6.35 | 1.62 | 0.50 | 0.13 | 0.06 | 0.02 |  |  |
| 5 | 9.60 | 2.44 | 0.76 | 0.20 | 0.09 | 0.03 |  |  |
| 6 | 13.46 | 3.43 | 1.06 | 0.28 | 0.13 | 0.04 | 0.02 |  |
| 7 | 17.91 | 4.56 | 1.41 | 0.37 | 0.18 | 0.05 | 0.02 |  |
| 8 | 22.93 | 5.84 | 1.80 | 0.47 | 0.22 | 0.07 | 0.03 |  |
| 9 |  | 7.26 | 2.24 | 0.59 | 0.28 | 0.08 | 0.03 |  |
| 10 |  | 8.82 | 2.73 | 0.72 | 0.34 | 0.10 | 0.04 | 0.01 |
| 12 |  | 12.37 | 3.82 | 1.01 | 0.48 | 0.14 | 0.06 | 0.02 |
| 14 |  | 16.46 | 5.08 | 1.34 | 0.63 | 0.19 | 0.08 | 0.03 |
| 16 |  |  | 6.51 | 1.71 | 0.81 | 0.24 | 0.10 | 0.04 |
| 18 |  |  | 8.10 | 2.13 | 1.01 | 0.30 | 0.13 | 0.04 |
| 20 |  |  | 9.84 | 2.59 | 1.22 | 0.36 | 0.15 | 0.05 |
| 22 |  |  | 11.74 | 3.09 | 1.46 | 0.43 | 0.18 | 0.06 |
| 24 |  |  | 13.79 | 3.63 | 1.72 | 0.51 | 0.21 | 0.07 |
| 26 |  |  | 16.00 | 4.21 | 1.99 | 0.59 | 0.25 | 0.09 |
| 28 |  |  |  | 4.83 | 2.28 | 0.68 | 0.29 | 0.10 |
| 30 |  |  |  | 5.49 | 2.59 | 0.77 | 0.32 | 0.11 |
| 35 |  |  |  | 7.31 | 3.45 | 1.02 | 0.43 | 0.15 |
| 40 |  |  |  | 9.36 | 4.42 | 1.31 | 0.55 | 0.19 |
| 45 |  |  |  | 11.64 | 5.50 | 1.63 | 0.69 | 0.24 |
| 50 |  |  |  | 14.14 | 6.68 | 1.98 | 0.83 | 0.29 |
| 55 |  |  |  |  | 7.97 | 2.36 | 0.35 | 0.35 |
| 60 |  |  |  |  | 9.36 | 2.78 | 1.17 | 0.41 |
| 65 |  |  |  |  | 10.86 | 3.22 | 1.36 | 0.47 |
| 70 |  |  |  |  | 12.46 | 3.69 | 1.56 | 0.54 |
| 75 |  |  |  |  | 14.16 | 4.20 | 1.77 | 0.61 |
| 80 |  |  |  |  |  | 4.73 | 1.99 | 0.69 |
| 85 |  |  |  |  |  | 5.29 | 2.23 | 0.77 |
| 90 |  |  |  |  |  | 5.88 | 2.48 | 0.86 |
| 95 |  |  |  |  |  | 6.50 | 2.74 | 0.95 |
| 100 |  |  |  |  |  | 7.15 | 3.01 | 1.05 |
| 150 |  |  |  |  |  | 15.15 | 6.38 | 2.22 |
| 200 |  |  |  |  |  |  | 10.87 | 3.78 |
| 300 |  |  |  |  |  |  |  | 8.01 |

NOTE: Based on C = 140

Table C.2 Friction Loss - PVC Schedule 40 Plastic Pipe

Pressure Loss From Friction in psi per 100 ft of Pipe

| Flow | Nominal Size | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (gpm) | 1/2" | 3/4" | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" |
| 1 | 0.32 | 0.11 | 0.03 | 0.01 | | | | |
| 2 | 1.14 | 0.39 | 0.12 | 0.03 | 0.02 | | | |
| 3 | 2.42 | 0.84 | 0.26 | 0.07 | 0.03 | 0.01 | | |
| 4 | 4.13 | 1.42 | 0.44 | 0.12 | 0.05 | 0.01 | | |
| 5 | 6.24 | 2.15 | 0.66 | 0.18 | 0.08 | 0.02 | 0.01 | |
| 6 | 8.75 | 3.02 | 0.93 | 0.25 | 0.12 | 0.03 | 0.02 | |
| 7 | 11.64 | 4.01 | 1.24 | 0.33 | 0.15 | 0.05 | 0.02 | |
| 8 | 14.90 | 5.14 | 1.59 | 0.42 | 0.20 | 0.06 | 0.02 | |
| 9 | 18.54 | 6.39 | 1.97 | 0.52 | 0.25 | 0.07 | 0.03 | |
| 10 | 22.53 | 7.77 | 2.40 | 0.63 | 0.30 | 0.09 | 0.04 | 0.01 |
| 11 | | 9.27 | 2.86 | 0.75 | 0.36 | 0.11 | 0.04 | 0.02 |
| 12 | | 10.89 | 3.36 | 0.89 | 0.42 | 0.12 | 0.05 | 0.02 |
| 14 | | 14.48 | 4.47 | 1.18 | 0.56 | 0.17 | 0.07 | 0.02 |
| 16 | | 18.55 | 5.73 | 1.51 | 0.71 | 0.21 | 0.09 | 0.03 |
| 18 | | | 7.13 | 1.88 | 0.89 | 0.26 | 0.11 | 0.04 |
| 20 | | | 8.66 | 2.28 | 1.08 | 0.32 | 0.13 | 0.05 |
| 22 | | | 10.33 | 2.72 | 1.29 | 0.38 | 0.16 | 0.06 |
| 24 | | | 12.14 | 3.20 | 1.51 | 0.45 | 0.19 | 0.07 |
| 26 | | | 14.08 | 3.17 | 1.75 | 0.52 | 0.22 | 0.08 |
| 28 | | | 16.15 | 4.25 | 2.01 | 0.60 | 0.25 | 0.09 |
| 30 | | | | 4.83 | 2.28 | 0.68 | 0.29 | 0.10 |
| 35 | | | | 6.43 | 3.04 | 0.90 | 0.38 | 0.13 |
| 40 | | | | 8.23 | 3.89 | 1.15 | 0.49 | 0.17 |
| 45 | | | | 10.24 | 4.48 | 1.43 | 0.60 | 0.21 |
| 50 | | | | 12.45 | 5.88 | 1.74 | 0.73 | 0.26 |
| 55 | | | | 14.85 | 7.01 | 2.08 | 0.88 | 0.30 |
| 60 | | | | | 8.24 | 2.44 | 1.03 | 0.36 |
| 65 | | | | | 9.56 | 2.83 | 1.19 | 0.41 |
| 70 | | | | | 10.96 | 3.25 | 1.37 | 0.48 |
| 75 | | | | | 12.46 | 3.69 | 1.56 | 0.54 |
| 80 | | | | | | 4.16 | 1.75 | 0.61 |
| 85 | | | | | | 4.66 | 1.96 | 0.68 |
| 90 | | | | | | 5.18 | 2.18 | 0.76 |
| 95 | | | | | | 5.72 | 2.41 | 0.84 |
| 100 | | | | | | 6.29 | 2.65 | 0.92 |
| 150 | | | | | | 13.33 | 5.62 | 1.95 |
| 200 | | | | | | | 9.57 | 3.33 |
| 250 | | | | | | | | 5.03 |
| 300 | | | | | | | | 7.05 |
| 350 | | | | | | | | 9.38 |

**NOTE:** All PVC pipe friction losses based on C = 150

Table C.3 **Friction Loss PVC Class 100 PSI Plastic Pipe**

Pressure Loss From Friction in psi per 100 ft of pipe

| Flow | | | | Nominal Size | | | |
|---|---|---|---|---|---|---|---|
| (gpm) | 3 1/2" | 4" | 5" | 6" | 8" | 10" | 12" |
| 50 | 0.09 | 0.05 | 0.02 | 0.01 | | | |
| 55 | 0.11 | 0.06 | 0.02 | 0.01 | | | |
| 60 | 0.13 | 0.07 | 0.03 | 0.01 | | | |
| 65 | 0.15 | 0.08 | 0.03 | 0.01 | | | |
| 70 | 0.17 | 0.09 | 0.03 | 0.01 | | | |
| 75 | 0.19 | 0.11 | 0.04 | 0.02 | 0.00 | | |
| 80 | 0.21 | 0.12 | 0.04 | 0.02 | 0.01 | | |
| 85 | 0.24 | 0.13 | 0.05 | 0.02 | 0.01 | | |
| 90 | 0.27 | 0.15 | 0.05 | 0.02 | 0.01 | | |
| 95 | 0.29 | 0.17 | 0.06 | 0.03 | 0.01 | | |
| 100 | 0.32 | 0.18 | 0.06 | 0.03 | 0.01 | | |
| 150 | 0.69 | 0.39 | 0.14 | 0.06 | 0.02 | 0.01 | |
| 200 | 1.17 | 0.66 | 0.23 | 0.10 | 0.03 | 0.01 | |
| 250 | 1.77 | 1.00 | 0.35 | 0.15 | 0.04 | 0.01 | |
| 300 | 2.48 | 1.39 | 0.50 | 0.21 | 0.06 | 0.02 | |
| 350 | 3.29 | 1.86 | 0.66 | 0.28 | 0.08 | 0.03 | |
| 400 | 4.22 | 2.38 | 0.85 | 0.36 | 0.10 | 0.03 | |
| 450 | 5.24 | 2.96 | 1.05 | 0.45 | 0.12 | 0.04 | |
| 500 | 6.38 | 3.59 | 1.28 | 0.55 | 0.15 | 0.05 | |
| 550 | 7.61 | 4.29 | 1.53 | 0.65 | 0.18 | 0.06 | |
| 600 | 8.94 | 5.04 | 1.79 | 0.77 | 0.21 | 0.07 | |
| 700 | | 6.70 | 2.39 | 1.02 | 0.28 | 0.09 | 0.04 |
| 800 | | 8.58 | 3.06 | 1.31 | 0.36 | 0.12 | 0.05 |
| 900 | | | 3.80 | 1.63 | 0.45 | 0.15 | 0.07 |
| 1000 | | | 4.62 | 1.98 | 0.55 | 0.18 | 0.08 |
| 1200 | | | 6.48 | 2.77 | 0.77 | 0.26 | 0.11 |
| 1400 | | | | 3.68 | 1.02 | 0.34 | 0.15 |
| 1600 | | | | 4.72 | 1.31 | 0.44 | 0.19 |
| 1800 | | | | 5.87 | 1.62 | 0.55 | 0.24 |
| 2000 | | | | | 1.97 | 0.66 | 0.29 |
| 2200 | | | | | 2.35 | 0.79 | 0.35 |
| 2400 | | | | | 2.77 | 0.93 | 0.41 |
| 2600 | | | | | 3.21 | 1.08 | 0.48 |
| 2800 | | | | | 3.68 | 1.24 | 0.55 |
| 3000 | | | | | 4.18 | 1.41 | 0.62 |
| 3200 | | | | | 4.71 | 1.58 | 0.70 |
| 3400 | | | | | | 1.77 | 0.79 |
| 3600 | | | | | | 1.97 | 0.88 |
| 3800 | | | | | | 2.18 | 0.97 |
| 4000 | | | | | | 2.39 | 1.06 |

**Based on C = 150**

Table C.4 **Friction Loss PVC Class 125 PSI Plastic Pipe**

Pressure Loss From Friction in psi per 100 ft of pipe

| Flow | Nominal Size | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (gpm) | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 3 1/2" | 4" |
| 1 | 0.02 | 0.01 | 0.00 | | | | | |
| 2 | 0.06 | 0.02 | 0.01 | 0.00 | | | | |
| 3 | 0.13 | 0.04 | 0.02 | 0.01 | | | | |
| 4 | 0.22 | 0.07 | 0.03 | 0.01 | 0.00 | | | |
| 5 | 0.33 | 0.10 | 0.05 | 0.02 | 0.01 | | | |
| 6 | 0.46 | 0.14 | 0.07 | 0.02 | 0.01 | | | |
| 7 | 0.62 | 0.19 | 0.09 | 0.03 | 0.01 | 0.00 | | |
| 8 | 0.79 | 0.24 | 0.12 | 0.04 | 0.02 | 0.01 | | |
| 9 | 0.98 | 0.30 | 0.15 | 0.05 | 0.02 | 0.01 | | |
| 10 | 1.19 | 0.36 | 0.18 | 0.06 | 0.02 | 0.01 | 0.00 | |
| 11 | 1.42 | 0.43 | 0.22 | 0.07 | 0.03 | 0.01 | 0.01 | |
| 12 | 1.67 | 0.51 | 0.25 | 0.09 | 0.03 | 0.01 | 0.01 | |
| 14 | 2.22 | 0.67 | 0.34 | 0.11 | 0.05 | 0.02 | 0.01 | |
| 16 | 2.85 | 0.86 | 0.43 | 0.15 | 0.06 | 0.02 | 0.01 | |
| 18 | 3.54 | 1.07 | 0.54 | 0.18 | 0.07 | 0.03 | 0.01 | |
| 20 | 4.31 | 1.30 | 0.65 | 0.22 | 0.09 | 0.03 | 0.02 | |
| 22 | 5.14 | 1.56 | 0.78 | 0.26 | 0.10 | 0.04 | 0.02 | |
| 24 | 6.04 | 1.83 | 0.92 | 0.31 | 0.12 | 0.05 | 0.02 | 0.00 |
| 26 | 7.00 | 2.12 | 1.06 | 0.36 | 0.14 | 0.05 | 0.03 | 0.02 |
| 28 | 8.03 | 2.43 | 1.22 | 0.41 | 0.16 | 0.06 | 0.03 | 0.02 |
| 30 | 9.13 | 2.76 | 1.39 | 0.47 | 0.18 | 0.07 | 0.04 | 0.02 |
| 35 | 12.14 | 3.68 | 1.84 | 0.62 | 0.25 | 0.09 | 0.05 | 0.03 |
| 40 | 15.55 | 4.71 | 2.36 | 0.80 | 0.31 | 0.12 | 0.06 | 0.04 |
| 45 | 19.34 | 5.86 | 2.94 | 0.99 | 0.39 | 0.15 | 0.08 | 0.04 |
| 50 | 23.50 | 7.12 | 3.57 | 1.21 | 0.48 | 0.18 | 0.10 | 0.05 |
| 55 | 28.04 | 8.49 | 4.26 | 1.44 | 0.57 | 0.22 | 0.11 | 0.06 |
| 60 | 32.94 | 9.98 | 5.00 | 1.69 | 0.67 | 0.26 | 0.13 | 0.08 |
| 65 | 38.21 | 11.57 | 5.80 | 1.96 | 0.77 | 0.30 | 0.16 | 0.09 |
| 70 | 43.83 | 13.27 | 6.65 | 2.25 | 0.89 | 0.34 | 0.18 | 0.10 |
| 75 | | 15.08 | 7.56 | 2.56 | 1.01 | 0.39 | 0.20 | 0.11 |
| 80 | | 17.00 | 8.52 | 2.88 | 1.14 | 0.44 | 0.23 | 0.13 |
| 85 | | 19.02 | 9.53 | 3.23 | 1.27 | 0.49 | 0.26 | 0.14 |
| 90 | | 21.14 | 10.60 | 3.59 | 1.41 | 0.54 | 0.28 | 0.16 |
| 95 | | 23.37 | 11.71 | 3.96 | 1.56 | 0.60 | 0.31 | 0.18 |
| 100 | | 25.69 | 12.88 | 4.36 | 1.72 | 0.66 | 0.35 | 0.19 |
| 150 | | | 27.30 | 9.24 | 3.64 | 1.40 | 0.73 | 0.41 |
| 200 | | | | 15.74 | 6.20 | 2.39 | 1.25 | 0.70 |
| 250 | | | | | 9.38 | 3.61 | 1.88 | 1.06 |
| 300 | | | | | 13.15 | 5.06 | 2.64 | 1.49 |
| 350 | | | | | 17.49 | 6.73 | 3.57 | 1.98 |
| 400 | | | | | | 8.62 | 4.50 | 2.53 |
| 450 | | | | | | 10.72 | 5.59 | 3.15 |
| 500 | | | | | | 13.03 | 6.80 | 3.83 |
| 550 | | | | | | | 8.11 | 4.57 |
| 600 | | | | | | | 9.53 | 5.37 |

Table C.4 (Cont'd) Friction Loss PVC Class 125 PSI Plastic Pipe

Pressure Loss From Friction in psi per 100 ft of pipe

| Flow | Nominal Size | | | | |
|---|---|---|---|---|---|
| (gpm) | 5" | 6" | 8" | 10" | 12" |
| 75 | 0.04 | 0.02 | 0.00 | | |
| 80 | 0.05 | 0.02 | 0.01 | | |
| 85 | 0.05 | 0.02 | 0.01 | | |
| 90 | 0.06 | 0.02 | 0.01 | | |
| 95 | 0.06 | 0.03 | 0.01 | | |
| 100 | 0.07 | 0.03 | 0.01 | | |
| 150 | 0.15 | 0.06 | 0.02 | 0.01 | |
| 200 | 0.25 | 0.11 | 0.03 | 0.01 | 0.00 |
| 250 | 0.38 | 0.16 | 0.04 | 0.02 | 0.01 |
| 300 | 0.53 | 0.23 | 0.06 | 0.02 | 0.01 |
| 350 | 0.71 | 0.30 | 0.08 | 0.03 | 0.01 |
| 400 | 0.90 | 0.39 | 0.11 | 0.04 | 0.02 |
| 450 | 1.12 | 0.48 | 0.13 | 0.05 | 0.02 |
| 500 | 1.37 | 0.58 | 0.16 | 0.06 | 0.02 |
| 600 | 1.91 | 0.82 | 0.23 | 0.08 | 0.03 |
| 650 | | 0.95 | 0.26 | 0.09 | 0.04 |
| 700 | | 1.09 | 0.30 | 0.10 | 0.05 |
| 750 | | 1.24 | 0.34 | 0.12 | 0.05 |
| 800 | | 1.39 | 0.39 | 0.13 | 0.06 |
| 850 | | 1.56 | 0.43 | 0.15 | 0.06 |
| 900 | | 1.73 | 0.48 | 0.16 | 0.07 |
| 950 | | 1.92 | 0.53 | 0.18 | 0.08 |
| 1000 | | 2.11 | 0.58 | 0.20 | 0.09 |
| 1100 | | 2.52 | 0.70 | 0.24 | 0.10 |
| 1200 | | 2.96 | 0.82 | 0.28 | 0.12 |
| 1300 | | 3.43 | 0.95 | 0.33 | 0.14 |
| 1400 | | 3.93 | 1.09 | 0.37 | 0.16 |
| 1500 | | 4.47 | 1.24 | 0.42 | 0.18 |
| 1600 | | 5.04 | 1.39 | 0.48 | 0.21 |
| 1700 | | 5.63 | 1.56 | 0.53 | 0.23 |
| 1800 | | 6.26 | 1.73 | 0.59 | 0.26 |
| 1900 | | | 1.92 | 0.66 | 0.29 |
| 2000 | | | 2.11 | 0.72 | 0.31 |
| 2200 | | | 2.51 | 0.86 | 0.38 |
| 2400 | | | 2.95 | 1.01 | 0.44 |
| 2600 | | | 3.43 | 1.17 | 0.51 |
| 2800 | | | 3.93 | 1.35 | 0.59 |
| 3000 | | | 4.47 | 1.53 | 0.67 |
| 3500 | | | | 2.04 | 0.89 |
| 4000 | | | | 2.61 | 1.14 |
| 4500 | | | | 3.24 | 1.41 |
| 5000 | | | | | 1.72 |

## Table C.5 Friction Loss - PVC Class 160 PSI Plastic Pipe

Pressure Loss from Friction in psi per 100 ft of Pipe

| Flow (gpm) | Nominal Size 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 4" |
|---|---|---|---|---|---|---|---|
| 1 | 0.02 | 0.01 | | | | | |
| 2 | 0.06 | 0.02 | 0.01 | | | | |
| 3 | 0.14 | 0.04 | 0.02 | | | | |
| 4 | 0.23 | 0.07 | 0.04 | 0.01 | | | |
| 5 | 0.35 | 0.11 | 0.05 | 0.02 | | | |
| 6 | 0.49 | 0.15 | 0.08 | 0.03 | 0.01 | | |
| 7 | 0.66 | 0.20 | 0.10 | 0.03 | 0.01 | | |
| 8 | 0.84 | 0.25 | 0.13 | 0.04 | 0.02 | | |
| 9 | 1.05 | 0.31 | 0.16 | 0.05 | 0.02 | | |
| 10 | 1.27 | 0.38 | 0.20 | 0.07 | 0.03 | 0.01 | |
| 11 | 1.52 | 0.45 | 0.23 | 0.08 | 0.03 | 0.01 | |
| 12 | 1.78 | 0.53 | 0.28 | 0.09 | 0.04 | 0.01 | |
| 14 | 2.37 | 0.71 | 0.37 | 0.12 | 0.05 | 0.02 | |
| 16 | 3.04 | 0.91 | 0.47 | 0.16 | 0.06 | 0.02 | |
| 18 | 3.78 | 1.13 | 0.58 | 0.20 | 0.08 | 0.03 | |
| 20 | 4.59 | 1.37 | 0.71 | 0.24 | 0.09 | 0.04 | 0.01 |
| 22 | 5.48 | 1.64 | 0.85 | 0.29 | 0.11 | 0.04 | 0.01 |
| 24 | 6.44 | 1.92 | 1.00 | 0.34 | 0.13 | 0.05 | 0.02 |
| 26 | 7.47 | 2.23 | 1.15 | 0.39 | 0.15 | 0.06 | 0.02 |
| 28 | 8.57 | 2.56 | 1.32 | 0.45 | 0.18 | 0.07 | 0.02 |
| 30 | 9.74 | 2.91 | 1.50 | 0.51 | 0.20 | 0.08 | 0.02 |
| 35 | | 3.87 | 2.00 | 0.68 | 0.27 | 0.10 | 0.03 |
| 40 | | 4.95 | 2.56 | 0.86 | 0.34 | 0.13 | 0.04 |
| 45 | | 6.16 | 3.19 | 1.08 | 0.42 | 0.16 | 0.05 |
| 50 | | 7.49 | 3.88 | 1.31 | 0.52 | 0.20 | 0.06 |
| 55 | | 8.93 | 4.62 | 1.56 | 0.62 | 0.24 | 0.07 |
| 60 | | 10.49 | 5.43 | 1.83 | 0.72 | 0.28 | 0.08 |
| 65 | | | 6.30 | 2.12 | 0.84 | 0.32 | 0.09 |
| 70 | | | 7.23 | 2.44 | 0.96 | 0.37 | 0.11 |
| 75 | | | 8.21 | 2.77 | 1.09 | 0.42 | 0.12 |
| 80 | | | 9.25 | 3.12 | 1.23 | 0.47 | 0.14 |
| 85 | | | 10.35 | 3.49 | 1.38 | 0.53 | 0.16 |
| 90 | | | | 3.88 | 1.53 | 0.59 | 0.17 |
| 95 | | | | 4.29 | 1.69 | 0.65 | 0.19 |
| 100 | | | | 4.72 | 1.86 | 0.72 | 0.21 |
| 150 | | | | 10.00 | 3.94 | 1.52 | 0.45 |
| 200 | | | | | 6.72 | 2.59 | 0.76 |
| 250 | | | | | 10.16 | 3.91 | 1.15 |
| 300 | | | | | | 5.49 | 1.61 |
| 350 | | | | | | 7.30 | 2.15 |
| 400 | | | | | | 9.35 | 2.75 |
| 450 | | | | | | | 3.42 |
| 500 | | | | | | | 4.15 |
| 550 | | | | | | | 4.96 |
| 600 | | | | | | | 5.82 |

Table C.5 (Cont'd) Friction Loss - PVC Class 160 PSI Plastic Pipe

Pressure Loss from Friction in psi per 100 ft of Pipe

| Flow<br>(gpm) | Nominal Size<br>5" | <br>6" | <br>8" | <br>10" | <br>12" |
|---|---|---|---|---|---|
| 50 | 0.02 | | | | |
| 55 | 0.02 | | | | |
| 60 | 0.03 | 0.01 | | | |
| 65 | 0.03 | 0.01 | | | |
| 70 | 0.04 | 0.02 | | | |
| 75 | 0.04 | 0.02 | | | |
| 80 | 0.05 | 0.02 | | | |
| 85 | 0.06 | 0.02 | | | |
| 90 | 0.06 | 0.03 | | | |
| 95 | 0.07 | 0.03 | | | |
| 100 | 0.08 | 0.03 | 0.01 | | |
| 150 | 0.16 | 0.07 | 0.02 | | |
| 200 | 0.27 | 0.12 | 0.03 | 0.01 | |
| 250 | 0.41 | 0.18 | 0.05 | 0.02 | |
| 300 | 0.58 | 0.25 | 0.07 | 0.02 | 0.01 |
| 350 | 0.77 | 0.33 | 0.09 | 0.03 | 0.01 |
| 400 | 0.98 | 0.42 | 0.12 | 0.04 | 0.02 |
| 450 | 1.22 | 0.52 | 0.14 | 0.05 | 0.02 |
| 500 | 1.48 | 0.63 | 0.18 | 0.06 | 0.03 |
| 550 | 1.77 | 0.76 | 0.21 | 0.07 | 0.03 |
| 600 | 2.08 | 0.89 | 0.25 | 0.08 | 0.04 |
| 650 | 2.41 | 1.03 | 0.29 | 0.10 | 0.04 |
| 700 | 2.77 | 1.18 | 0.33 | 0.11 | 0.05 |
| 750 | 3.14 | 1.34 | 0.37 | 0.13 | 0.06 |
| 800 | 3.54 | 1.51 | 0.42 | 0.14 | 0.06 |
| 850 | 3.96 | 1.69 | 0.47 | 0.16 | 0.07 |
| 900 | 4.41 | 1.88 | 0.52 | 0.18 | 0.08 |
| 950 | 4.87 | 2.08 | 0.58 | 0.20 | 0.09 |
| 1000 | 5.36 | 2.29 | 0.63 | 0.22 | 0.09 |
| 1100 | 6.39 | 2.73 | 0.76 | 0.26 | 0.11 |
| 1200 | | 3.20 | 0.89 | 0.30 | 0.13 |
| 1300 | | 3.72 | 1.03 | 0.35 | 0.15 |
| 1400 | | 4.26 | 1.18 | 0.40 | 0.18 |
| 1500 | | 4.84 | 1.34 | 0.46 | 0.20 |
| 1600 | | | 1.51 | 0.52 | 0.23 |
| 1700 | | | 1.69 | 0.58 | 0.25 |
| 1800 | | | 1.88 | 0.64 | 0.28 |
| 1900 | | | 2.08 | 0.71 | 0.31 |
| 2000 | | | 2.29 | 0.78 | 0.34 |
| 2500 | | | 3.46 | 1.18 | 0.52 |
| 3000 | | | | 1.66 | 0.72 |
| 3500 | | | | 2.20 | 0.96 |
| 4000 | | | | 2.82 | 1.23 |
| 4500 | | | | | 1.53 |
| 5000 | | | | | 1.86 |

### Table C.6 Friction Loss - PVC Class 200 PSI Plastic Pipe

Pressure Loss from Friction in psi per 100 ft of Pipe

| Flow | Nominal Size | | | | | | |
|---|---|---|---|---|---|---|---|
| (gpm) | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" | 4" |
| 1 | 0.02 | 0.01 | | | | | |
| 2 | 0.07 | 0.02 | 0.01 | | | | |
| 3 | 0.14 | 0.04 | 0.02 | | | | |
| 4 | 0.24 | 0.08 | 0.04 | 0.01 | | | |
| 5 | 0.36 | 0.12 | 0.06 | 0.02 | | | |
| 6 | 0.51 | 0.16 | 0.08 | 0.03 | 0.01 | | |
| 7 | 0.67 | 0.22 | 0.11 | 0.04 | 0.01 | | |
| 8 | 0.86 | 0.28 | 0.14 | 0.05 | 0.02 | | |
| 9 | 1.07 | 0.34 | 0.18 | 0.06 | 0.02 | | |
| 10 | 1.30 | 0.42 | 0.22 | 0.07 | 0.03 | 0.01 | |
| 11 | 1.56 | 0.50 | 0.26 | 0.09 | 0.03 | 0.01 | |
| 12 | 1.83 | 0.59 | 0.30 | 0.10 | 0.04 | 0.02 | |
| 14 | 2.43 | 0.78 | 0.40 | 0.14 | 0.05 | 0.02 | |
| 16 | 3.11 | 1.00 | 0.52 | 0.17 | 0.07 | 0.03 | |
| 18 | 3.87 | 1.24 | 0.64 | 0.22 | 0.09 | 0.03 | |
| 20 | 4.71 | 1.51 | 0.78 | 0.26 | 0.10 | 0.04 | 0.01 |
| 22 | 5.62 | 1.80 | 0.93 | 0.32 | 0.12 | 0.05 | 0.01 |
| 24 | 6.60 | 2.12 | 1.09 | 0.37 | 0.15 | 0.06 | 0.02 |
| 26 | 7.65 | 2.46 | 1.27 | 0.43 | 0.17 | 0.07 | 0.02 |
| 28 | 8.78 | 2.82 | 1.46 | 0.49 | 0.19 | 0.07 | 0.02 |
| 30 | 9.98 | 3.20 | 1.66 | 0.56 | 0.22 | 0.09 | 0.02 |
| 35 | | 4.26 | 2.20 | 0.75 | 0.29 | 0.11 | 0.03 |
| 40 | | 5.45 | 2.82 | 0.95 | 0.38 | 0.14 | 0.04 |
| 45 | | 6.78 | 3.51 | 1.19 | 0.47 | 0.18 | 0.05 |
| 50 | | 8.24 | 4.26 | 1.44 | 0.57 | 0.22 | 0.06 |
| 55 | | 9.83 | 5.09 | 1.72 | 0.68 | 0.26 | 0.08 |
| 60 | | 11.55 | 5.97 | 2.02 | 0.80 | 0.31 | 0.09 |
| 65 | | | 6.93 | 2.35 | 0.93 | 0.36 | 0.10 |
| 70 | | | 7.95 | 2.69 | 1.06 | 0.41 | 0.12 |
| 75 | | | 9.03 | 3.06 | 1.21 | 0.46 | 0.14 |
| 80 | | | 10.18 | 3.44 | 1.36 | 0.52 | 0.15 |
| 85 | | | | 3.85 | 1.52 | 0.59 | 0.17 |
| 90 | | | | 4.28 | 1.69 | 0.65 | 0.19 |
| 95 | | | | 4.74 | 1.87 | 0.72 | 0.21 |
| 100 | | | | 5.21 | 2.06 | 0.79 | 0.23 |
| 150 | | | | 11.04 | 4.36 | 1.68 | 0.49 |
| 200 | | | | | 7.43 | 2.85 | 0.84 |
| 250 | | | | | | 4.31 | 1.27 |
| 300 | | | | | | 3.05 | 1.78 |
| 350 | | | | | | 8.05 | 2.36 |
| 400 | | | | | | | 3.03 |
| 450 | | | | | | | 3.77 |
| 500 | | | | | | | 4.58 |
| 550 | | | | | | | 5.46 |
| 600 | | | | | | | 6.42 |

Table C.6 (Cont'd) Friction Loss PVC Class 200 PSI Plastic Pipe

Pressure Loss from Friction in psi per 100 ft of Pipe

| Flow | Nominal Size | | | | |
|---|---|---|---|---|---|
| (gpm) | 5" | 6" | 8" | 10" | 12" |
| 50 | 0.02 | | | | |
| 55 | 0.03 | | | | |
| 60 | 0.03 | 0.01 | | | |
| 65 | 0.04 | 0.02 | | | |
| 70 | 0.04 | 0.02 | | | |
| 75 | 0.05 | 0.02 | | | |
| 80 | 0.05 | 0.02 | | | |
| 85 | 0.06 | 0.03 | | | |
| 90 | 0.07 | 0.03 | | | |
| 95 | 0.08 | 0.03 | | | |
| 100 | 0.08 | 0.04 | 0.01 | | |
| 150 | 0.18 | 0.08 | 0.02 | | |
| 200 | 0.30 | 0.13 | 0.04 | 0.01 | |
| 250 | 0.45 | 0.19 | 0.05 | 0.02 | |
| 300 | 0.63 | 0.27 | 0.07 | 0.03 | 0.01 |
| 350 | 0.84 | 0.36 | 0.10 | 0.03 | 0.01 |
| 400 | 1.08 | 0.46 | 0.13 | 0.04 | 0.02 |
| 450 | 1.34 | 0.57 | 0.16 | 0.05 | 0.02 |
| 500 | 1.63 | 0.70 | 0.19 | 0.07 | 0.03 |
| 550 | 1.95 | 0.83 | 0.23 | 0.08 | 0.03 |
| 600 | 2.29 | 0.98 | 0.27 | 0.09 | 0.04 |
| 650 | 2.65 | 1.14 | 0.31 | 0.11 | 0.05 |
| 700 | 3.04 | 1.30 | 0.36 | 0.12 | 0.05 |
| 750 | 3.46 | 1.48 | 0.41 | 0.14 | 0.06 |
| 800 | 3.90 | 1.67 | 0.46 | 0.16 | 0.07 |
| 850 | 4.36 | 1.87 | 0.52 | 0.18 | 0.08 |
| 900 | 4.85 | 2.07 | 0.57 | 0.20 | 0.09 |
| 950 | 5.36 | 2.29 | 0.63 | 0.22 | 0.09 |
| 1000 | 5.89 | 2.52 | 0.70 | 0.24 | 0.10 |
| 1100 | 7.03 | 3.01 | 0.83 | 0.28 | 0.12 |
| 1200 | | 3.53 | 0.98 | 0.33 | 0.15 |
| 1300 | | 4.10 | 1.13 | 0.39 | 0.17 |
| 1400 | | 4.70 | 1.30 | 0.45 | 0.19 |
| 1500 | | 5.34 | 1.48 | 0.51 | 0.22 |
| 1600 | | 6.02 | 1.66 | 0.57 | 0.25 |
| 1700 | | | 1.86 | 0.64 | 0.28 |
| 1800 | | | 2.07 | 0.71 | 0.31 |
| 1900 | | | 2.29 | 0.78 | 0.34 |
| 2000 | | | 2.52 | 0.86 | 0.38 |
| 2500 | | | 3.80 | 1.30 | 0.57 |
| 3000 | | | | 1.83 | 0.80 |
| 3500 | | | | 2.43 | 1.06 |
| 4000 | | | | 3.11 | 1.36 |
| 4500 | | | | 3.87 | 1.69 |
| 5000 | | | | | 2.05 |

Table C.7 **Friction Loss - PVC Class 315 PSI Plastic Pipe**

Pressure Loss from Friction in psi per 100 ft of Pipe

| Flow | Nominal Size | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (gpm) | 1/2" | 3/4" | 1" | 1 1/4" | 1 1/2" | 2" | 2 1/2" | 3" |
| 1 | 0.22 | 0.07 | 0.02 | 0.01 | | | | |
| 2 | 0.78 | 0.27 | 0.09 | 0.03 | 0.01 | | | |
| 3 | 1.65 | 0.56 | 0.19 | 0.06 | 0.03 | 0.01 | | |
| 4 | 2.82 | 0.96 | 0.32 | 0.10 | 0.05 | 0.02 | | |
| 5 | 4.26 | 1.45 | 0.48 | 0.16 | 0.08 | 0.03 | 0.01 | |
| 6 | 5.97 | 2.03 | 0.67 | 0.22 | 0.11 | 0.04 | 0.02 | |
| 7 | 7.95 | 2.70 | 0.90 | 0.29 | 0.15 | 0.05 | 0.02 | |
| 8 | 10.18 | 3.45 | 1.15 | 0.37 | 0.19 | 0.06 | 0.03 | |
| 9 | 12.66 | 4.30 | 1.43 | 0.46 | 0.24 | 0.08 | 0.03 | |
| 10 | 15.38 | 5.22 | 1.74 | 0.56 | 0.29 | 0.10 | 0.04 | 0.01 |
| 11 | 18.35 | 6.23 | 2.07 | 0.67 | 0.35 | 0.12 | 0.05 | 0.02 |
| 12 | 21.56 | 7.32 | 2.43 | 0.79 | 0.41 | 0.14 | 0.05 | 0.02 |
| 14 | | 9.74 | 3.24 | 1.05 | 0.54 | 0.18 | 0.07 | 0.03 |
| 16 | | 12.47 | 4.15 | 1.34 | 0.70 | 0.23 | 0.09 | 0.04 |
| 18 | | 15.51 | 5.16 | 1.67 | 0.87 | 0.29 | 0.12 | 0.04 |
| 20 | | 18.86 | 6.27 | 2.03 | 1.05 | 0.35 | 0.14 | 0.05 |
| 22 | | | 7.48 | 2.42 | 1.25 | 0.42 | 0.17 | 0.06 |
| 24 | | | 8.79 | 2.84 | 1.47 | 0.50 | 0.20 | 0.08 |
| 26 | | | 10.19 | 3.29 | 1.71 | 0.58 | 0.23 | 0.09 |
| 28 | | | 11.69 | 3.78 | 1.96 | 0.66 | 0.26 | 0.10 |
| 30 | | | 13.29 | 4.29 | 2.23 | 0.75 | 0.30 | 0.11 |
| 35 | | | 17.68 | 5.71 | 2.96 | 1.00 | 0.39 | 0.15 |
| 40 | | | | 7.31 | 3.80 | 1.28 | 0.51 | 0.19 |
| 45 | | | | 9.10 | 4.72 | 1.59 | 0.63 | 0.24 |
| 50 | | | | 11.06 | 5.74 | 1.94 | 0.76 | 0.29 |
| 55 | | | | 13.19 | 6.85 | 2.31 | 0.91 | 0.35 |
| 60 | | | | 15.50 | 8.04 | 2.71 | 1.07 | 0.41 |
| 65 | | | | | 9.33 | 3.15 | 1.24 | 0.48 |
| 70 | | | | | 10.70 | 3.61 | 1.42 | 0.55 |
| 75 | | | | | 12.16 | 4.10 | 1.62 | 0.62 |
| 80 | | | | | 13.71 | 4.62 | 1.82 | 0.70 |
| 85 | | | | | | 5.17 | 2.04 | 0.78 |
| 90 | | | | | | 5.75 | 2.27 | 0.87 |
| 95 | | | | | | 6.35 | 2.51 | 0.96 |
| 100 | | | | | | 6.99 | 2.76 | 1.06 |
| 150 | | | | | | 14.81 | 5.84 | 2.24 |
| 200 | | | | | | | 9.95 | 3.82 |
| 250 | | | | | | | | 5.77 |
| 300 | | | | | | | | 8.09 |

# APPENDIX D

## UNIPLOT FOR LATERAL LINE AND SUBMAIN DESIGN

(From "Micro Irrigation Design Manual" Hardie Irrigation)

Uniplot curves are used to design submains and laterals with many discharge outlets where the flow decreases uniformly (i.e., rectangular-shaped fields). Uniplot is a simple and versatile design tool; it may be used to design submains and laterals of one or many pipe sizes, and it may be used in the design of submains and laterals on non-uniform (undulating) terrain. The steps which follow serve to illustrate the proper use of the Uniplot System.

PROCEDURE

1. Calculate the Specific Discharge Rate (SDR).

   SDR = Total Discharge/Total Length

2. Use this SDR to determine the working curve to be used for each pipe size from the working curve nomograph. See Figures D.2 and D.3. Lay a ruler along the diagonal line for the appropriate SDR as determined above. At the point where this line intersects the horizontal line for the actual internal diameter of the pipe being used, read off the working curve to be used on the working curve axis. Internal diameters for PVC pipes are given in Table D.1.

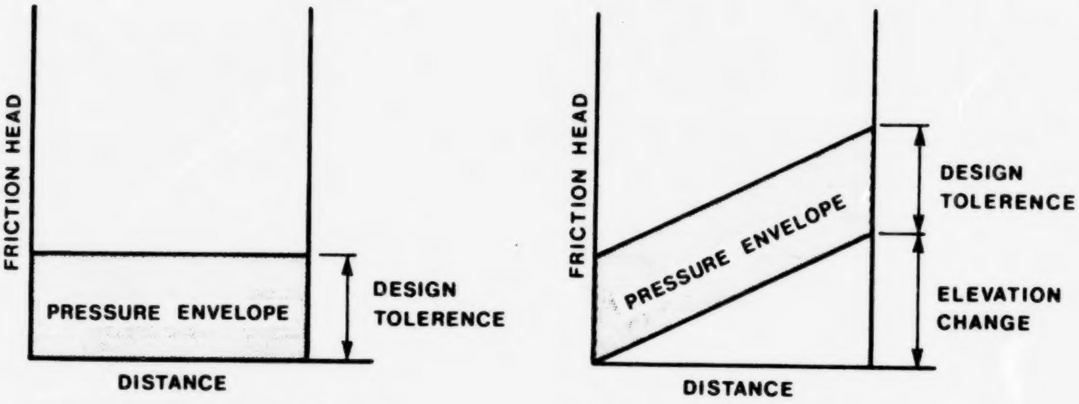
Table D.1 Internal Diameters for PVC Pipe

| Nominal Pipe Size (in) | Schedule or Class | Working Pressure (psi) | Inside Diameter (in) |
|---|---|---|---|
| 1/2" | 40 | 600 | 0.622 |
| | 80 | 850 | 0.546 |
| | 200 | 200 | 0.680 |
| 3/4" | 40 | 480 | 0.824 |
| | 80 | 690 | 0.742 |
| | 200 | 200 | 0.890 |
| 1" | 40 | 450 | 1.049 |
| | 80 | 630 | 0.957 |
| | 200 | 200 | 1.155 |
| 1 1/4" | 40 | 370 | 1.380 |
| | 80 | 520 | 1.278 |
| | 200 | 200 | 1.500 |
| 1 1/2" | 160 | 160 | 1.740 |
| | 200 | 200 | 1.720 |
| 2" | 160 | 160 | 2.193 |
| | 200 | 200 | 2.149 |
| 2 1/2" | 160 | 160 | 2.655 |
| | 200 | 200 | 2.601 |
| 3" | 160 | 160 | 3.230 |
| | 200 | 200 | 3.116 |

3. Place a sheet of tracing paper over the Uniplot curves (Figure D.6). Draw the vertical and horizontal axes. Draw a vertical line at the distance along the horizontal axis equal to the length of the pipeline.

   For level ground: Draw a line above the horizontal axis at a height equal to the design tolerance for the emitter used.

   For sloping ground: Assuming the pipeline is running downhill, draw a line from the bottom left hand corner (origin) to the elevation change at the other end of the pipeline. Draw a second line parallel to this line and separated from it by a VERTICAL distance equal to the design tolerance for the emitter being used. This creates the pressure envelope.



FOR LEVEL GROUND

FOR SLOPING GROUND

Figure D.1 Determination of Pressure Envelopes for Uniplot

4. Start at the closed end of the pipeline and match the working curves determined in Step 2 to the pressure envelope determined in Step 3. The tracing paper can be moved vertically but the vertical axis of the curves and tracing paper must remain aligned.

5. Segments of different working curves may be used for various pipe sizes to arrive at a submain or lateral design.

6. The design requirement will be met provided the working curves are within the pressure envelope.

The following possibilities can occur:

(i) If one curve is completely contained in the pressure envelope for the entire pipe length, then a single pipe diameter can be selected for the pipeline design.

(ii) If more than one curve is completely contained within the pressure envelope, a choice of pipe diameters is possible. The smallest diameter will be the most economical. However, selecting the curve which is most nearly parallel the contour envelope will give the least pressure variation along the pipe. (A contour envelope is not necessarily a straight line but follows the land surface shape.)

(iii) If there is no single curve contained in the pressure envelope then a single pipe diameter is not adequate and a pipe size change somewhere along the line must be made.

Example 1 (For level ground)

A 400 ft lateral is to be laid on level ground with 1 gph emitters installed every 4 ft. The pressure variation along the lateral must not exceed 5 ft. Use polyethylene to size the lateral.

$$\text{SDR} = \frac{1\ \text{gph}}{4\ \text{ft}} = 0.25\ \text{gph/ft}$$

From Figure D.5 - The working curves for an SDR of 0.25 for 13 mm is 17
15 mm is 19.5
16 mm is 21
20 mm is 27

Use Figure D.6

Lay a piece of tracing paper over the Uniplot curves and trace the axes. At the 400 ft distance on the distance axis, place a point 5 ft above the axis and draw a horizontal line to the friction loss axis. The area beneath this line represents the pressure envelope.

Keeping the axes aligned trace the working curves #17, 19.5, 21 and 27 onto the tracing paper as shown in Figure D.2

For this example note that working curve number 21 most closely approaches the allowable design tolerance of 5 ft without exceeding this pressure loss. The least expensive design would be to select 16 mm I.D. polyethylene hose for the 400 ft lateral line subjected to the condition stated in this example.

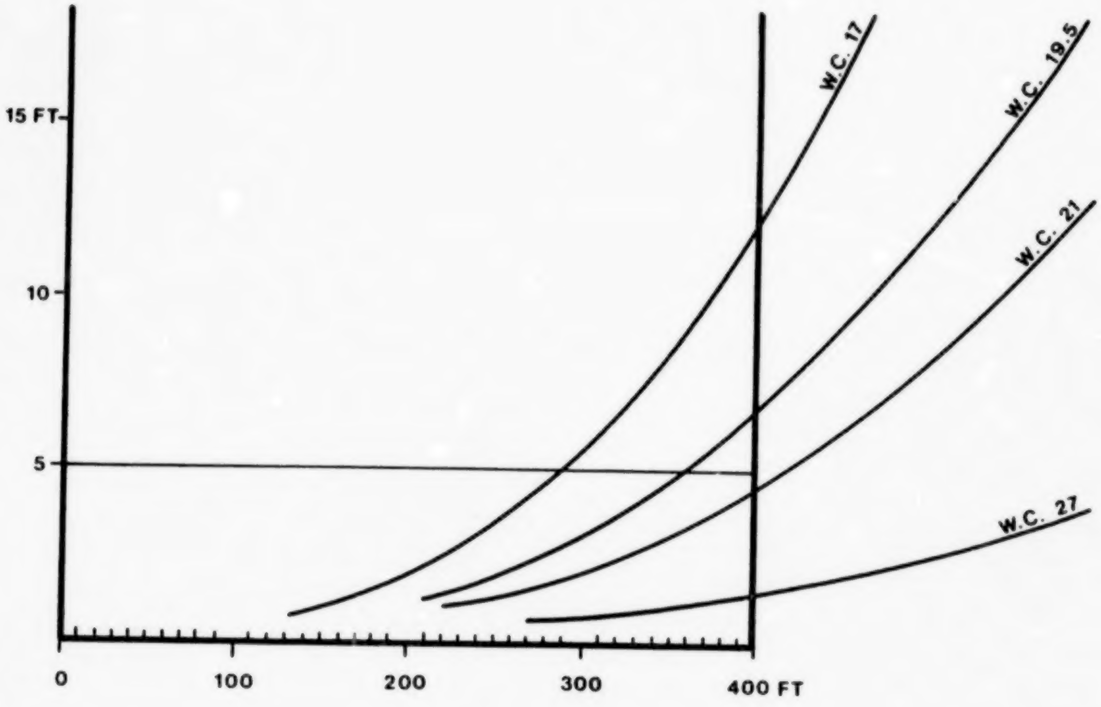


Figure D.2 Using Uniplot for a Lateral on Level Ground

Example 2 (For sloping ground)

A 500 ft lateral line is to be laid on a 2% slope (downhill) with 1 gph emitters installed every 3 ft. The pressure variation along the lateral must not exceed 5 ft. Using polyethylene line, size the lateral.

$$SDR = \frac{1 \text{ gph/ft}}{3 \text{ ft}}$$

$$= 0.33 \text{ gph/ft}$$

From Figure D.5 - the working curve for an SDR of 0.33 for

13 mm polyethylene is 15
16 mm polyethylene is 19
20 mm polyethylene is 24

A 2% slope for 500 ft is an elevation drop of 10 ft.

Lay a sheet of tracing paper over the Uniplot curves and trace over the axes. At the 500 ft mark on the distance axis, place a point 10 ft above the axis and draw a line from the point to the origin. This line represents the 2% land slope

Draw a second line parallel to the first but 5 feet above it. These two lines represent the pressure envelope for a 5 ft pressure variation.

Keeping the vertical axis aligned, slide the tracing paper downwards and trace working curve 15 within the pressure envelope. Note that the curve is fully within the pressure envelope from 0 to 290 ft. (See Figure D.3) Trace working curves 19 and 24 ensuring that the maximum portion of the curves remain within the pressure envelope. When tracing curve 24, position the tracing paper so that the curve passes through the maximum boundary point of 15 ft at the 500 ft length as this will minimize the lateral cost.

Mark the lengths where the traced working curves intersect. The intersected points mark the length of 13 mm, 16 mm and 20 mm hose required to make up the lateral.

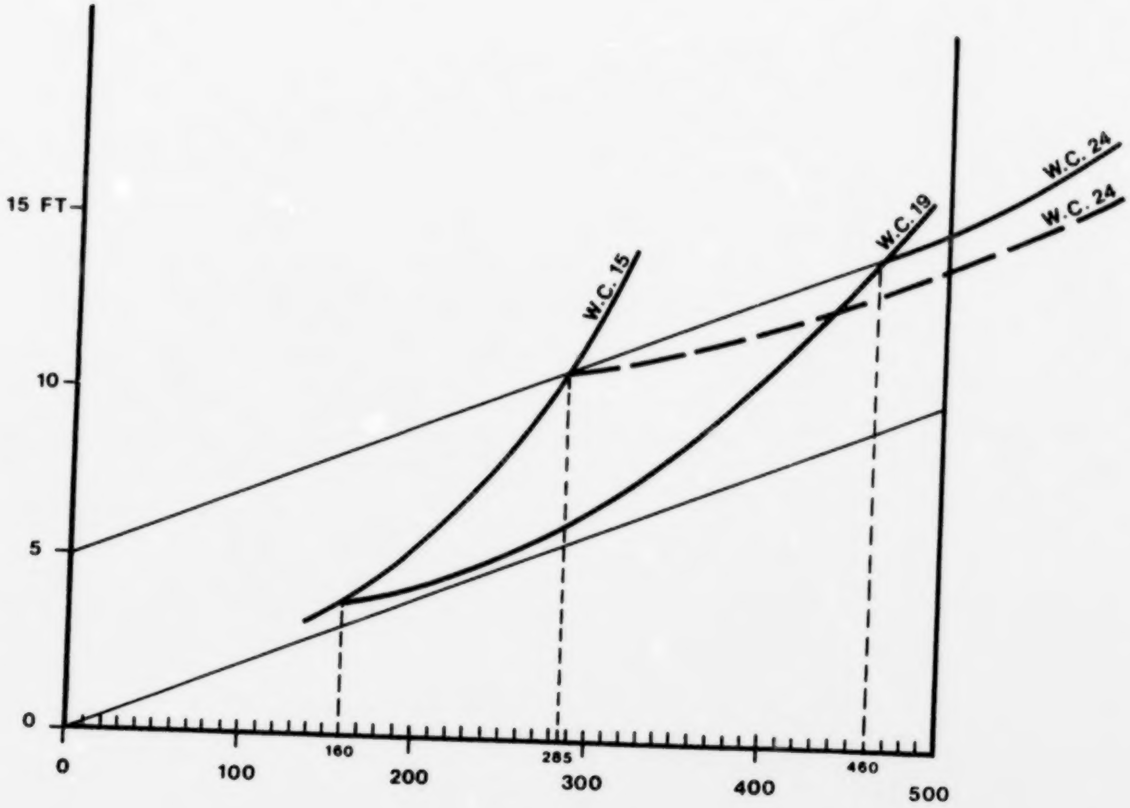


Figure D.3 Using Uniplot for a Lateral on Sloping Ground

Two possibilities for the lateral design would be:

(i) 160 ft 13 mm, 300 ft 16 mm and 40 ft 20 mm

or (ii) 285 ft 13 mm, 215 ft of 24 mm

The most economical design will be selection number (i).

Figure D.4 **SPECIFIC DISCHARGE RATE FOR PVC PIPE (gph/ft)**

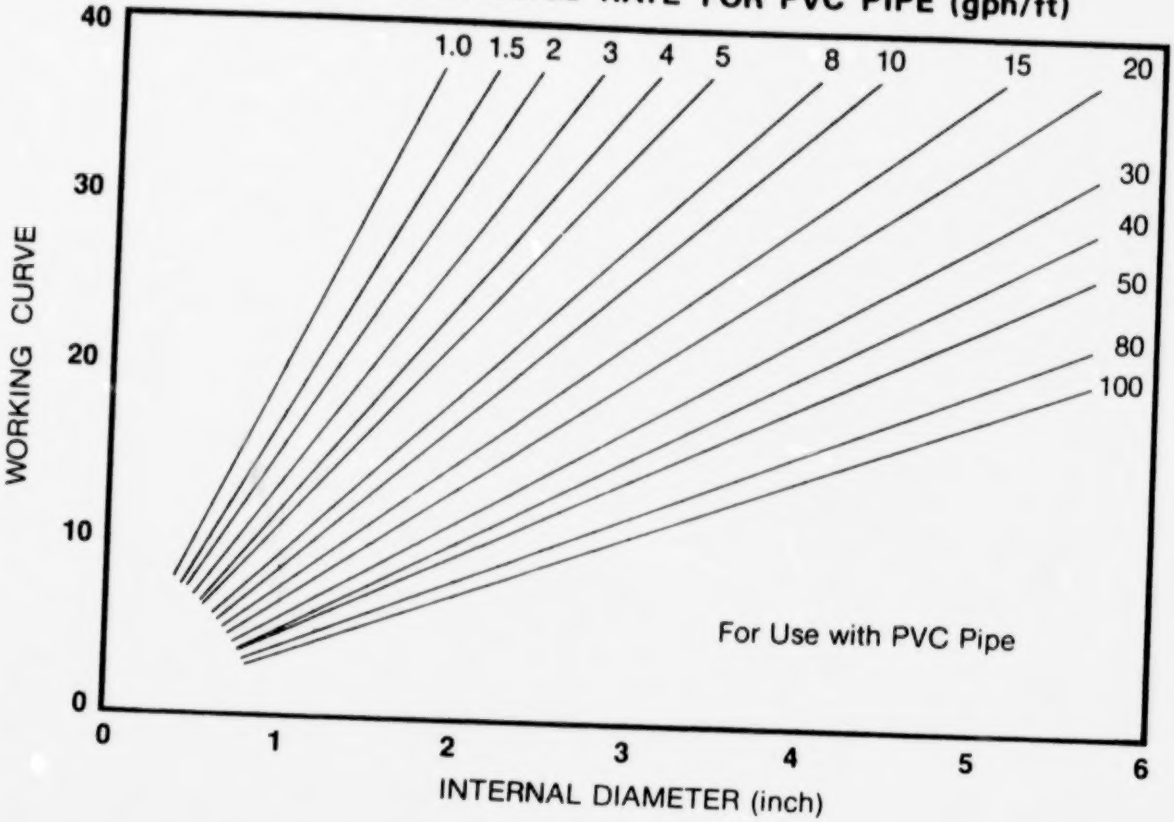


Figure D.5 **SPECIFIC DISCHARGE RATE FOR POLYETHYLENE HOSE (gph/ft)**

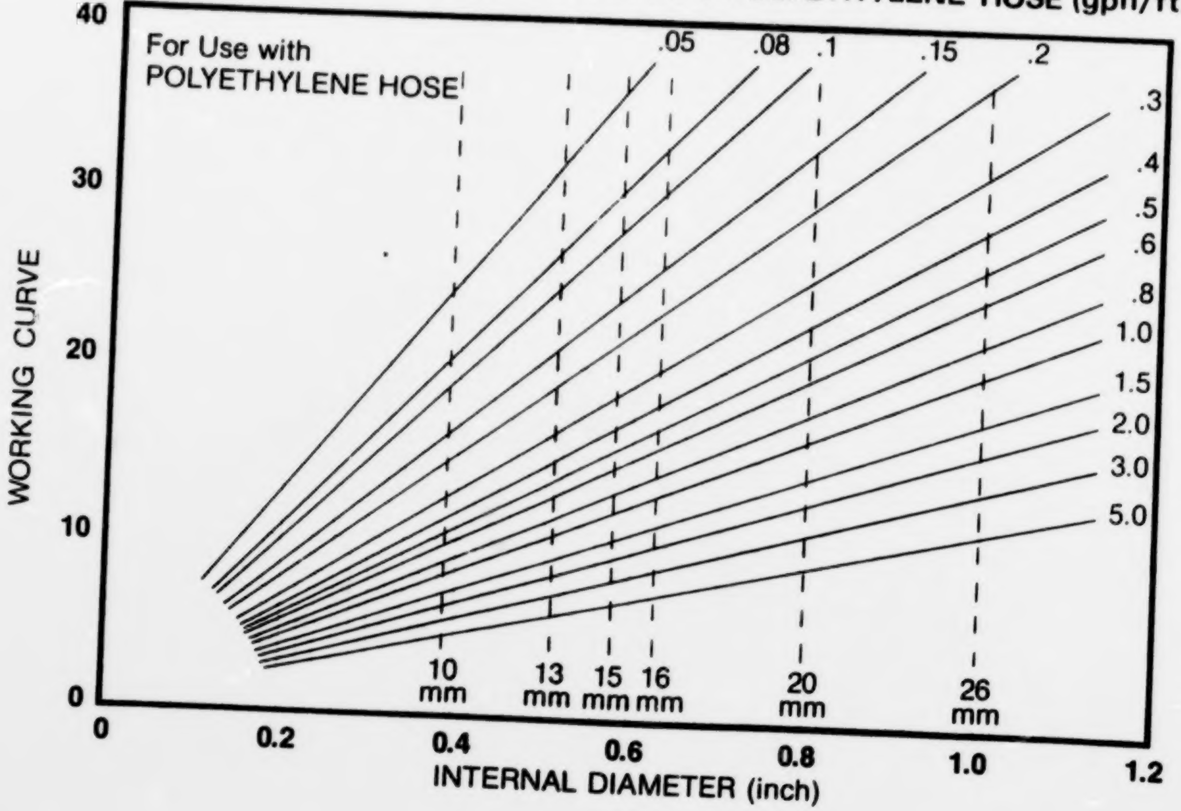
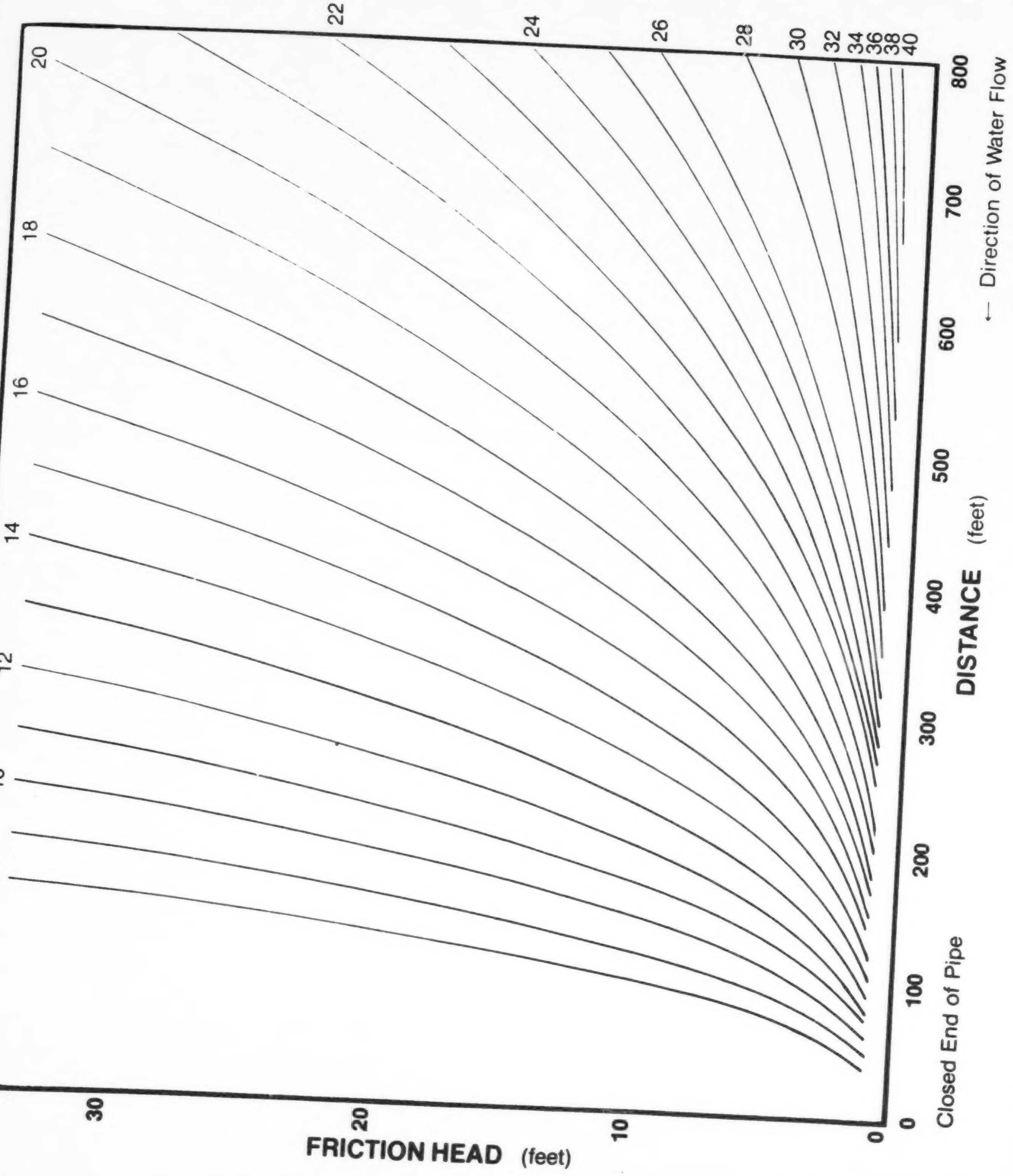


Figure D.6

## UNIPLOT DESIGN CURVES



# APPENDIX E

## TRICKLE IRRIGATION DESIGN INFORMATION SHEET

This manual provides a systematic approach to trickle irrigation system design. Sample plans on Pages 2-16 and 2-17 figuritively describe the planning and layout requirements for a trickle irrigation system. The following design sheet is a blank form of the design information presented on the sample plans. The designer should be conversant with trickle irrigation design principles and parameters presented in this manual before proceeding with any design. Additional copies of these "trickle irrigation design information" sheets are available from the Engineering Branch, B.C. Ministry of Agriculture and Fisheries.

### TRICKLE IRRIGATION DESIGN INFORMATION

**CROP AND SOILS REPORT**

| Pit | Crop | Root Depth (ft) | Availability Coefficient | Soil Texture | A.W.S.C. (in/ft) | Max Lateral Water movement. radius (ft) |
|---|---|---|---|---|---|---|
| A | ____ | ____ | ____ | ____ | ____ | ____ |
| B | ____ | ____ | ____ | ____ | ____ | ____ |
| C | ____ | ____ | ____ | ____ | ____ | ____ |

**DESIGN PARAMETERS**

Evapotranspiration Rate (ET) ________ in/day
Effective Soil Water Storage Capacity ________ inches
Effective Soil Water Storage Factor (S) ________
Plant Spacing ____ x ____ ft$^2$
Plant Area (A) ________ ft$^2$
Crop Coefficient Factor (K) ________

**PLANT WATER REQUIREMENTS**

Gallons/Plant/Day = 0.623 x ____ (ET) in/day x ____ S x ____ A ft$^2$ x ____ K = ________ G/P/D

Trickle System Design Requirement TC = $\frac{\text{G/P/D} \times 1.1}{0.90}$ = ________ G/P/D

**DESIGN DATA**

Emitter Type ________
Emitter Operating Pressure ________ psi
Emitter Discharge ________ gph
Emitter Spacing ________ ft
Emitters per Plant ________

Zone Operating Time per Day ________ hrs/day
Zone Flow Rate ________ gpm
Water Source Capacity ________ gpm
Pressure at Water Source ________ psi

Total System Operating Time = ____ hrs/zone x ____ zones = ________ hrs

**FILTRATION REQUIREMENTS**

Water Source ________
Water Quality Ca, Mg, Na, K ________ mg/l
Fe ________ mg/l
S ________ mg/l
pH ________

Screen Mesh Size or Sand Media Selection ________

## ZONE FRICTION LOSS CALCULATION

**Maximum Pressure Variation in Zone** ________ psi
**Maximum Lateral Length** ________ ft

**Average Flow per foot in lateral** = $\frac{\text{emitter flow rate}}{\text{emitter spacing}}$ = $\frac{\text{\_\_\_\_ gph}}{\text{\_\_\_\_ ft}}$ = ________ gph/ft

**Lateral line friction loss =**

______ ft - ______ inch ______ pipe @ ______ $\frac{\text{gph}}{\text{ft}}$ = ________ psi

Emitter Barb Loss (30% of lateral Line Loss) = ________ psi

Elevation Difference ____ ft = ________ psi

**Total Lateral Pressure Loss** = ________ psi

**Header Line Friction Loss**

| Section | Flow | Pipe Length | Pipe Size | Friction Loss |
|---|---|---|---|---|
| ______ | ______ gpm | ______ ft | ______ in | ______ psi |
| ______ | ______ | ______ | ______ | ______ |
| ______ | ______ | ______ | ______ | ______ |
| ______ | ______ | ______ | ______ | ______ |
| ______ | ______ | ______ | ______ | ______ |
| ______ | ______ | ______ | ______ | ______ |
| ______ | ______ | ______ | ______ | ______ |
| ______ | ______ | ______ | ______ | ______ |

Total Friction ________ psi

Header Line Fitting Loss (additional 20%) ________ psi

Elevation Difference ______ ft = ________ psi

**Total Header Line Pressure Loss** ________ psi

**Total Zone Pressure Loss**

Header Loss _____ psi + Lateral Line loss _____ psi = ________ psi

## MAINLINE FRICTION LOSS CALCULATION

x - x ____ ' - ____ " ____ @ ____ gpm - ____ x ____ = ________ psi
x - x ____ ' - ____ " ____ @ ____ gpm - ____ x ____ = ________ psi
x - x ____ ' - ____ " ____ @ ____ gpm - ____ x ____ = ________ psi
x - x ____ ' - ____ " ____ @ ____ gpm - ____ x ____ = ________ psi

**Total Friction Loss in Mainline** ________ psi

## SYSTEM PRESSURE REQUIREMENT

Pressure Required at Zone Control ________ psi
Total Friction Loss in Mainline ________ psi
Elevation ____ ft. = ________ psi
Miscellaneous Losses (Mainline valves, fittings, etc.) ________ psi

Total Pressure Requirement = ________ psi

= ________ ft

## SYSTEM FLOW REQUIREMENT

____ gpm/zone x ____ zones operating at one time = ________ gpm

## HORSEPOWER REQUIREMENT

H.P. = $\frac{\text{\_\_\_\_\_\_\_\_ ft x \_\_\_\_\_\_\_\_ gpm}}{\text{3960 x \_\_\_\_\_ \%}}$ = ________ h.p.

# APPENDIX F

## METRIC CONVERSION TABLE

### Flow

| | | | |
|---|---|---|---|
| 1 gallon per minute (U.S) | = | 3.78 | litres per minute |
| 1 gallon per minute (Imp) | = | 4.55 | litres per minute |
| 1 cubic foot per sec (cfs) | = | 1700 | litres per minute |
| 1 cubic foot per sec (cfs) | = | 0.028 | cubic metre per second |

### Volume

| | | | |
|---|---|---|---|
| 1 gallon (U.S) | = | 3.78 | litres |
| 1 gallon (Imp) | = | 4.55 | litres |
| 1 cubic foot | = | 28.32 | litres |
| | = | 7.48 | gallons (U.S.) |
| 1 cubic metre | = | 1000 | litres |
| | = | 35.3 | cubic feet |
| | = | 264 | gallons (U.S.) |

### Area

| | | | |
|---|---|---|---|
| 1 acre | = | 0.405 | hectares |
| | = | 43,560 | square feet |
| 1 hectare | = | 2.47 | acres |

### Length

| | | | |
|---|---|---|---|
| 1 inch | = | 2.54 | centimetres |
| | = | 25.4 | millimetres |
| 1 ft | = | 30.48 | centimetres |
| 1 metre | = | 3.28 | feet |
| 1 mile | = | 1.61 | kilometres |

### Pressure

| | | | |
|---|---|---|---|
| 1 atmosphere | = | 101.3 | kilopascals |
| | = | 29.92 | inches of Hg @ 32°F |
| | = | 33.94 | feet of water @ 62°F |
| | = | 14.7 | pounds per square inch |
| 1 pound per square inch | = | 6.90 | kilopascals |
| | = | 0.70 | metre of head of water |
| | = | 2.31 | feet of head of water |
| 1 bar | = | 0.98 | atmosphere |
| | = | 100 | kilopascals |
| | = | 14.5 | pounds per square inch |

### Energy

| | | | |
|---|---|---|---|
| 1 horsepower (h.p.) | = | 0.746 | kilowatts |

### Concentration

| | | | |
|---|---|---|---|
| 1 ppm | = | 1 | mg/L |

## GLOSSARY

| | |
|---|---|
| Application Efficiency | A ratio of the net amount of water applied to the gross amount delivered by the irrigation system. |
| Application Uniformity | The variance in flow from the emitter discharging the lowest flow rate to the emitter with the highest flow rate. |
| Availability Coefficient | The maximum fraction of available water storage capacity to be removed before irrigation is required. |
| Available Water Storage Capacity | The amount of soil water retained between field capacity and the permanent wilting point. |
| Backflow Preventor | A device that prevents water from reversing its flow and thereby protects the water supply system from possible contamination. |
| Crop Coefficient Factor | Adjustment used for the plants' daily water requirement in relation to canopy, root area, plant shape and spacing. |
| Effective Rooting Depth | That depth in the soil above which the roots obtain 90% or more of their water between irrigations. |
| Effective Soil Water Storage Capacity | The amount of water stored in the soil that is available for crop use. |
| Emitter | A device used in trickle irrigation for pressure dissipation to obtain a desired low flow rate. |
| Equivalence | An equivalent weight is the weight in grams of an atom or radical divided by the valence of the atom or radical. (Equivalence is the weight of a substance which combines with or replaces one gram-atomic weight of hydrogen.) A milliequivalence is 1/1000th of an equivalent. |
| Evapotranspiration | The total of water transpired by plants and evaporated from the soil surface. |
| Header Line | Also called a submain, this line supplies water to the lateral lines. |
| Lateral Line | Pipelines that supply water to the emitters. |

| | |
|---|---|
| Root Area | The lateral area occupied by the root system of a plant. |
| Total Dynamic Head | The energy exerted by the pump which is equal to the sum of static lift, friction head, static discharge head and pressure head. |
| Zone | A portion of an irrigation system that is controlled by one valve. |

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